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RESOURCE RECOVERY & REUSE SERIES 9

9

Energy Recovery from Domestic and Agro-waste Streams in Uganda: A Socioeconomic Assessment

Solomie Gebrezgabher, Sena Amewu, Avinandan Taron and Miriam Otoo

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Solomie Gebrezgabher, Sena Amewu, Avinandan Taron and Miriam Otoo

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CONTENTS

List of Tables vii

List of Figures ix

Acronyms and Abbreviations x

Summary xi

1. Introduction 1

2. Description of Energy Business Models 2

3. Overall Approach to Socioeconomic Impact Assessment 2

3.1 Description of Scenarios 3

3.2 Environmental Impact Assessment of Energy Business Models 4

3.3 Financial Analysis of Energy Business Models 4

4. Dry Fuel Manufacturing Business Model 5

4.1 Technological Options for Dry Fuel Manufacturing Model 5

4.1.1 Raw Materials Used for Briquette Production 5

4.1.2 Human Excreta as Input for Briquette Production 5

4.1.3 Briquetting Process 6

4.2 Environmental Impact Assessment of Dry Fuel Manufacturing Model 7

4.2.1 System Boundary 7

4.2.2 Agricultural Residue under the Baseline Scenario 7

4.2.3 Agricultural Residue Transportation and Briquetting 8

4.2.4 Briquette Transportation and Combustion 8

4.2.5 Net Environmental Impact of Dry Fuel Manufacturing Model 8

4.3 Social Impacts of Dry Fuel Manufacturing Model 10

4.3.1 Additional Income for Farmers from the Sale of Agricultural Residue 10

4.3.2 Savings for End Users 12

4.3.3 Health Impacts 12

4.4 Financial Analysis of Dry Fuel Manufacturing Model 12

4.5 Consolidated Socioeconomic Results of the Dry Fuel Manufacturing Model 13

5. Energy Service Company (ESCO) Model 15

5.1 Technological Options for the ESCO Model 15
5.1.1 Raw Materials Used for Gasification 16
5.1.2 Gasification Process 16
5.2 Environmental Impact Assessment of the ESCO Model 17
5.2.1 System Boundary 17
5.2.2 Source of Energy for End Users under the Baseline Scenario 17
5.2.3 Agricultural Residue under the Baseline Scenario 17
5.2.4 Transportation and Gasification of Agricultural Residue 18
5.2.5 Net Environmental Impact of the ESCO Model 18
5.3 Social Impacts of the ESCO Model 20
5.3.1 Savings for End Users 20
5.3.2. Additional Income to Farmers and Job Creation 21
5.3.3 Health Impacts 21
5.4 Financial Analysis of the ESCO Model 22
5.5 Consolidated Socioeconomic Results of the ESCO Model 24
6. Onsite Energy Generation Model 24
6.1 Technological Options for the Onsite Energy Generation Model 24
6.1.1 Fixed Dome Model 25
6.1.2 Floating Drum 25
6.2 Environmental Impact Assessment of the Onsite Energy Generation Model 25
6.2.1 System Boundary 25
6.2.2 Source of Energy for End Users under the Baseline Scenario 25
6.2.3 Human Excreta under the Baseline Scenario 26
6.2.4 Biogas Production 26
6.2.5 Net Environmental Impact of the Onsite Energy Generation Model 26
6.3 Social Impacts of the Onsite Energy Generation Model 29
6.3.1 Savings in Energy Cost for End Users 29
6.3.2 Health Expenditure Savings 29
6.3.3 Time Savings from Access to Toilet Service 30

6.4 Financial Analysis of the Onsite Energy Generation Model 30

6.5 Consolidated Socioeconomic Results of the Onsite Energy Generation Model 31

7. Sensitivity Analysis - Stochastic Simulation 31

7.1 Stochastic Variables 31

7.2 Simulation Results of Business Models....33

7.2.1 Simulation Results of the Dry Fuel Manufacturing Model 33

7.2.2 Simulation Results of the ESCO Model 34

7.2.3 Simulation Results of the Onsite Energy Generation Model 35

8. Discussion and Conclusion 36

9. References 38

LIST OF TABLES

Table 1. Baseline and Alternative Scenarios 4

Table 2. Environmental Impact Categories 4

Table 3. Agricultural Residues Available and Their Ash Content in Uganda 5

Table 4. Emission Factors for Open Burning of Agricultural Residues under the Baseline Scenario....7

Table 5. CO_2 Emissions from Transportation of Agro-residues to the Briquette Plant 8

Table 6. Emission Factors from Combustion of Firewood and Briquette 9

Table 7. Emission Savings from Avoided Use of Firewood and Burning Agro-residues (Kg of ....

Emmission/Kg of Briquette) 9

Table 8. Environmental Emissions from the Production and Use of 1 Kg of Briquette 9

Table 9. Annual Value of GHG Emission Reduction from Briquette Business (2,000 Tons) 11

Table 10. Savings to End Users from Using Briquettes....12

Table 11. Capital Cost of Briquette Plant (USD)....13

Table 12. Input Parameters for Financial Analysis of Dry Fuel Manufacturing Model....14

Table 13. Financial Results of Briquette Business (USD)....14

Table 14. Net Socioeconomic Results of Dry Fuel Manufacturing Business 15

Table 15. GHG Emissions Associated with Kerosene Use and Diesel Generators under Baseline Scenario 17

Table 16. Emission Factors for Open Burning of Agricultural Residue under the Baseline Scenario. 17

Table 17. CO_2 Emissions from the Gasification Plant (Transportation of Agro-waste and Gasification)................18

Table 18. Emission Savings/KWh of Electricity Generated by the ESCO Model (Kg/KWh) 18

Table 19. GHG Emissions/KWh of Electricity Generated under the ESCO Model (Kg CO_2-eq/KWh) 19

Table 20. Annual Value of GHG Emission Reduction from the ESCO Model (120 KW).......................................20

Table 21. General Information on Alternative Energy Use 20

Table 22. Savings in Energy Costs for End Users from Using Electricity from ESCO (USD/year) 21

Table 23. Capital Costs for Gasifier System...22

Table 24. Input Parameters for Financial Analysis of the ESCO Model 23

Table 25. Financial Results of the ESCO Model (USD)...23

Table 26. Net Socioeconomic Results of the ESCO Model..24

Table 27. Gas Yield Potential of Human and Livestock Waste 25

Table 28. Emission Factors from Combustion of Fuelwood 26

Table 29. Methane (CH_4) Emissions from Human Excreta..26

Table 30. GHG Emissions from a Biogas Plant...26

Table 31. Emission Savings/m³ of Biogas Generated by the Onsite Energy Model 27

Table 32. GHG Emissions/m³ of Biogas Generated (kg CO_2-eq/m³) 27

Table 33. Annual Value of GHG Emission Reduction from the Onsite Energy Generation Model 28

Table 34. Incremental Costs and Benefits from Shifting to Biogas for End Users 29

Table 35. Income Streams and Operational Costs for the Onsite Energy Generation Model 30

Table 36. Financial Results of the Onsite Energy Generation Business Model (USD)...31

Table 37. Net Socioeconomic Results of the Onsite Energy Generation Model..32

Table 38. Stochastic Variables in the Simulation Models...32

Table 39. Simulation Results of the Dry Fuel Manufacturing Model 33

Table 40. Simulation Results of the ESCO Model 34

Table 41. Simulation Results of the Onsite Energy Generation Model 35

Table 42. Comparisons of the Socioeconomic Results of Energy Business Models...37

LIST OF FIGURES

Figure 1. Conceptual Framework for Assessing the Economic Impact of Resource Recovery and Reuse (RRR) Business Models 3

Figure 2. Process Diagram of Briquetting 6

Figure 3. GHG Emissions and Savings from 2,000 tons of Briquettes (Tons of CO_2eq/year) 10

Figure 4. Other Emission Savings from 2,000 tons of Briquettes (Tons/year) 11

Figure 5. Process Diagram of Gasification 16

Figure 6. GHG Emissions and Savings from a 120 KW Capacity Gasification Plant (Tons CO_2-eq/year) 19

Figure 7. Schematic of the Onsite Energy Generation Business Model 25

Figure 8. GHG Emissions and Savings From Four Public Toilet Complexes with Biogas Plant 28

Figure 9. Probability Density Function of NPVs for Dry Fuel Manufacturing Model 34

Figure 10. Probability Density Function of NPVs for ESCO Model 35

Figure 11. Probability Density Function of NPVs for Onsite Energy Generation Model 36

ACRONYMS AND ABBREVIATIONS

BCR	Benefit-cost ratio
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
ESCO	Energy Services Company
GHG	Greenhouse gas
IRR	Internal rate of return
KW	Kilowatt
KWh	Kilowatt hour
LPG	Liquefied petroleum gas
MJ	Mega Joule
MSW	Municipal solid waste
N_2O	Nitrous oxide
NO_x	Nitrogen oxide
NPV	Net present value
O&M	Operation and maintenance
ROI	Return on investment
RRR	Resource recovery and reuse
SO_2	Sulfur dioxide
VAT	Value added tax
VER	Voluntary Emission Reduction

SUMMARY

Most of the domestic and agro-waste in African cities end up in open dumps and natural water bodies thus causing severe environmental and health problems. These waste streams have resources such as nutrient and energy that can be valorized by transforming them into valuable products. As most cities in Africa grapple with the challenge of energy security, recovering energy from waste offers dual benefits – a) improved waste management, and b) provision of reliable energy to households, institutions and commercial entities. The International Water Management Institute (IWMI) has developed a number of waste-to-energy business models and has undertaken a feasibility analysis of selected models in several cities across the globe.

In this report we present a socioeconomic assessment of three energy business models, based on feasibility studies carried out in Kampala, Uganda. We assess the potential economic, environmental and social impacts of waste-to-energy business models and provide decision makers with overall cost and benefits of the models to the society and thus justify the need for undertaking such investments. To assess environmental impacts, a life cycle of emissions of agricultural residue and fecal sludge-derived energy sources is evaluated using indicators such as CO_2, CH_4 and N_2O for climate change and other emissions such as SO_2 and NO_x. A baseline scenario and a system boundary for the business models are identified and a comparison is made of costs and benefits of the model versus a business-as-usual scenario. To assess the sensitivity of the socioeconomic assessment results to variation in input variables, a simulation model of the business models is developed using a Monte Carlo simulation. The following is a brief description of the business models along with the baseline scenario and system boundary for socioeconomic assessment:

- **Dry fuel manufacturing (briquette) model** – The business processes agricultural residues to produce briquettes to be used for cooking and heating in households, large institutions and small and medium energy-intensive industries. The assessment was done for a production unit of 2,000 tons of noncarbonized briquettes. Firewood is the most widely used energy source for institutional and commercial use in Kampala and therefore it was taken as the reference system. Agricultural residue, an input raw material in the briquetting process, is burnt in open fields during land preparation for planting crops. The system boundary for the model contains collection and transportation of agricultural residue, briquetting, product distribution and combustion in stoves.

- **Energy Service Company (ESCO) model** – The business processes agricultural residues to generate electricity which is sold to households, institutions and commercial businesses through a mini grid. The business is assumed to have a generation capacity of 120 KW. The baseline scenario used is households' use of kerosene for lighting and the use of diesel generators for commercial and public centers. The system boundary for the model contains collection and transportation of agricultural residue and generation and distribution of electricity.

- **Onsite energy generation model** – The business is initiated by enterprises providing sanitation services such as public toilets and treat human waste in a biodigester to generate biogas used for lighting or cooking. The assessment was done for a toilet complex serving 600-1,000 users a day with a 54 m^3 biogas plant. The baseline scenario used open defecation in slums. Biogas is sold to small eateries that previously used fuelwood for cooking. The system boundary for the model contains operations of toilet facilities and production and use of biogas.

The main conclusions of this report can be summarized as follows:

- The dry fuel manufacturing and onsite energy generation models were found to be financially and economically viable while the ESCO model was not financially viable due to high investment costs and low electricity prices.

- A sensitivity analysis shows that the dry fuel manufacturing model and onsite energy generation model have more than an 80 and a 99% chance, respectively, of economic success. The ESCO model is not financially viable; however, it is feasible with a positive Net Present Value (NPV) and Benefit-Cost Ratio (BCR) of greater than 1 when social benefits and costs are included.

- The combustion of briquettes in stoves contributes the highest greenhouse gas (GHG) and other (SO_2 and NO_2) emissions while for the ESCO model, the highest contribution to GHG emissions is from the gasification process.

- The business models, in addition to combating deforestation and climate change, generate additional income to farmers, create jobs for local residents and enable end users to save on energy costs. Replacing kerosene lamps or diesel generators with electricity from the ESCO model has the potential to reduce the expenditures incurred by households and other end users. Under the onsite energy generation model, although there is a need for additional investment in cooking stoves for end users when shifting to biogas, the estimated value of net savings in energy costs are higher than the one-time investment in cooking stoves.

- The major contribution to the socioeconomic feasibility of the business models is from the social benefits and thus exclusion of social benefits could lead to erroneous investment decisions with potentially many investment projects being ignored.

1. INTRODUCTION

The quality and sustainability of the urban environment, the efficiency and productivity of the urban economy and the health and well-being of the public are determined by, among other things, the existing waste management systems in the region (Schubeler et al. 1996). Due to lack of resources and ability to plan and implement sewage systems, liquid and solid waste management is inadequate in low-income countries (Arthur et al. 2011). A significant portion of the population in low-income countries, where houses are often built before the construction of sewage systems and other infrastructural necessities, does not have access to a waste collection service and only a fraction of the generated waste is actually collected (Arthur et al. 2011; Schubeler et al. 1996). The insufficient collection and inappropriate disposal of liquid and solid wastes are source of water, land and air pollution, and pose risks to human health and the environment.

Nowadays, governments, private-sector organizations and international development agencies are exploring and promoting opportunities to recover and reuse energy from different waste streams by applying an array of waste-to-energy processes. Energy recovery from organic fractions of different waste streams has the dual advantage of solving the prevailing waste management problems while providing sustainable energy solutions to the different sectors of the economy. The need for alternative sources of energy has been recognized not only in developed countries but also in developing countries. Energy plays a critical role in the development process of a country. The economic prosperity and quality of life of a country are closely linked to the level of its per capita energy consumption (Singh and Sooch 2004). The provision of reliable, secure and affordable energy services is a key factor in providing basic human needs that not only improve the quality of life but ensure sustainable development (Amigun et al. 2011). Access to energy or the lack of it affects all aspects of development, including livelihoods, access to water, agricultural productivity, health, population levels, education and gender-related issues (Amigun et al. 2011).

In developing countries, a large portion of households rely on traditional biomass as the primary source of energy. Wood is the most common example, but the use of animal dung and crop residues is also widespread. Approximately 60% of the world's total wood removals from forests and outside forests is used for energy purposes (IEA 2006). While the developed countries use only 30% of wood for energy, the developing countries use 80% for the same purpose (IEA 2006). In sub-Saharan Africa, 76% of the region's population depends on traditional biomass as the primary energy source with fuelwood, such as firewood and charcoal, as the biggest source of biomass energy (IEA 2006). In Uganda, over 90% of the national energy demand is met from biomass sources (Ferguson 2012) while in Rwanda it is 88% (KIST 2006). In Ghana, fuelwood accounts for about 72% of total primary energy supply (Arthur et al. 2011) while in Kenya fuelwood is the most important source of energy, meeting over 70% of the country's total energy consumption needs (GVEP International 2010). In Nepal, the largest source of fuel is fuelwood which accounted for 87% of the total energy consumed in the country (IDS-Nepal 2008); other similar examples can be cited. This continued overdependence on fuelwood and other forms of biomass as the primary source of energy has adverse effects on forest resources and on people's health as burning biomass causes indoor air pollution. Ghana's forest cover, for instance, has declined from 8.13 million hectares (Mha) at the beginning of the last century to 1.6 Mha today (KITE 2008). According to FAO estimates, the rate of deforestation in Ghana is 3%/year (Arthur et al. 2011) while Uganda is losing 50,000 ha (0.8%) of its forestland/year through deforestation. The major cause of this continuing dependence on fuelwood is lack of affordable and reliable alternative sources of energy.

The realization that deforestation and fuelwood shortages are likely to become pressing problems in many low-income countries, has spurred significant interest in other waste-to-energy business models. Waste processing business models such as dry fuel manufacturing (briquetting), biogas and gasification or energy service company models have the potential to counteract many adverse health and environmental impacts connected with traditional biomass energy. However, the viability and sustainability of these energy business models depend, among other factors, on the prices of charcoal and firewood and existing regulations or lack of enforcement of regulations on the use of forest-based resources. The availability of cheap firewood and charcoal has been part of the reason why households and other institutional users rely on these biomasses. These low prices result from the fact that fuelwood can be tapped with little or no direct cost to producers or consumers.

The potential economic, environmental and social impacts of waste-to-energy business models need to be assessed to ensure their sustainable development. Assessing the socioeconomic impact of waste-to-energy business models is an important tool for decision making in order to ensure that the energy business models result in desired socioeconomic benefits to society and thus justify their development and promotion. This study evaluated the socioeconomic impacts of three energy business models in Kampala. The business models considered in this study are:

- Dry fuel manufacturing (briquette) model.
- Energy Service Company (ESCO) model.
- Onsite energy generation model.

The socioeconomic analysis is conducted based on the valuation of financial, environmental and social benefits and costs associated with the business models.

The remainder of the report is organized as follows: Section 2 describes the business models considered in this study; section 3 outlines the general approach used to assess the socioeconomic impacts of the business models; sections 4, 5 and 6 contain detailed socioeconomic impact assessments of each business model; and sections 7 and 8 contain the sensitivity analysis of the results and conclusion.

2. DESCRIPTION OF ENERGY BUSINESS MODELS

The dry fuel manufacturing business model processes agricultural residues to produce briquettes which can be used for cooking or heating in households, institutions or commercial enterprises. The business model is assumed to have a capacity of producing 2,000 tons of noncarbonized biomass fuel briquettes/year. The capacity of the plant is determined based on the largest briquette plant operating in Kampala. The inputs used for briquetting are agricultural residues such as coffee husks, rice husks, wheat, groundnuts and sawdust, which are sourced from farmers in the surrounding area. At the plant, the agricultural residues are sieved, pulverized using a hammer mill and dried to a moisture content of 13% using a flash drier. The agricultural residues are then blended to get a homogeneous mixture of different materials. The mixed biomass is fed into a briquetting machine to be compacted. The business model uses a hammer mill to pulverize the raw materials, flash drier to dry and piston presses to compact the raw materials.

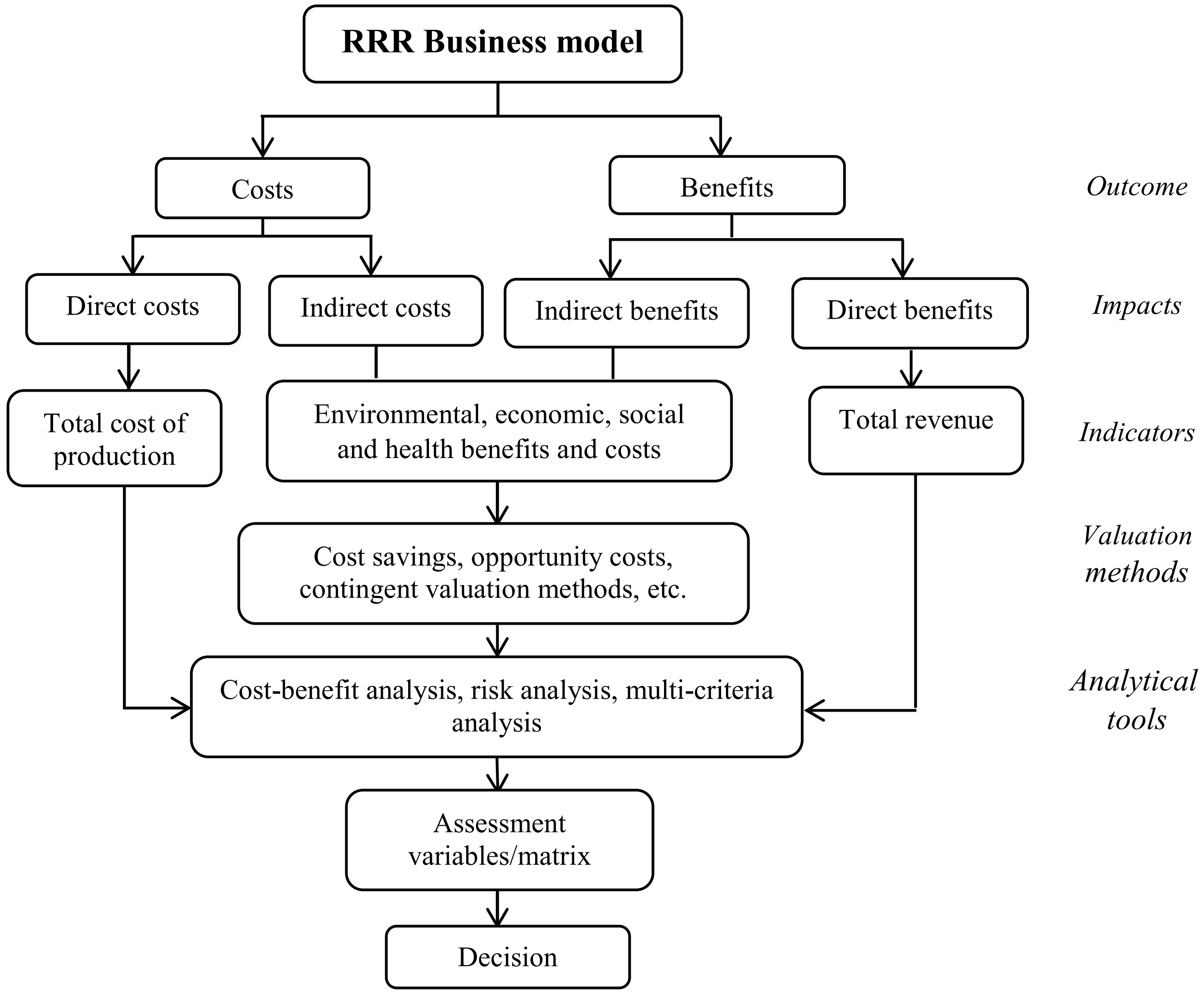
The onsite energy generation model uses an integrated approach to address sanitation and energy needs of the poor simultaneously. The business model provides sanitation services and generates biogas from human waste which can be used onsite or sold to other users depending on how the business is implemented. The business model is equipped with a toilet complex, with eight toilets having a capacity of serving 600-1,000 users a day. In this study the biogas model applied is the fixed dome digester model which is the most widely used type in Africa. Biogas plants with a digester volume between 6 and 16 m^3 are commonly used for households and small institutions while large institutions usually require digesters of volumes between 30 and 50 m^3 (Renwick et al. 2007; AFD and AWSB 2010). The analysis in this study is for four plants and the toilet complexes will serve a target population of 3,190 while the biogas generated by each of the toilet complexes will be supplied to adjacent or nearby institutional and commercial users such as restaurants. Each toilet complex has a capacity of serving, on average, 800 persons/day and has a biogas plant volume of 54 m^3.

The ESCO model processes crop residues to generate electricity which is sold to households, institutions and commercial businesses through a mini grid. The inputs used for gasification are agricultural residues, mainly corncobs, which are sourced from farmers in the surrounding area. The business is assumed to have a generation capacity of 120 KW.

3. OVERALL APPROACH TO SOCIOECONOMIC IMPACT ASSESSMENT

The socioeconomic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al. 2011). In contrast to a financial analysis, a socioeconomic analysis provides a more comprehensive investigation on the effects of a proposed project, takes a broader perspective and determines the project's overall value to society. The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, governments and other stakeholders outside of the business (Figure 1).

FIGURE 1. CONCEPTUAL FRAMEWORK FOR ASSESSING THE ECONOMIC IMPACT OF RESOURCE RECOVERY AND REUSE (RRR) BUSINESS MODELS.



The analysis also includes the benefits and costs that cannot be readily measured using observable market prices and costs (De Souza et al. 2011). In this study, the financial viability of the business was assessed through a cost-benefit analysis and for the environmental impacts, a life cycle of emissions of organic-waste-derived energy sources is evaluated.

3.1 Description of Scenarios

In conducting a socioeconomic analysis of any project, it is important to determine the baseline scenario which will be the benchmark to compare project alternatives. This study assessed the economic viability of the business model and a comparison of the costs and benefits of the business model versus a business as usual scenario. Table 1 shows the baseline and alternative scenarios considered in this study. Under the dry fuel manufacturing business model, fuelwood is the most widely used energy source for institutional and commercial use in Kampala and therefore was taken as the reference system. For the briquettes produced, we assumed a replacement of fuelwood for use in institutions and commercial sectors for heating and cooking. For the agricultural residue used as input in the briquetting process, we assumed that under the baseline scenario, the residues are burnt in open fields during land preparation for planting crops (Okello et al. 2013). The agricultural residues used in the briquette making are sourced from farmers which are spread over a large geographical area.

The baseline scenario for the ESCO model is that households derive energy for their lighting needs from kerosene while electricity supply for commercial centers and other public centers are derived from diesel generators. Agricultural residues such as corncobs used in the gasification process are sourced from farmers spread over a large geographical area.

The situation under the baseline scenario for the onsite energy generation model is that a large number of people in densely populated commercial centers find it difficult to access a decent toilet and therefore resort to the practice of open defecation in the nearby bush and around city centers. The main source of fuel for cooking for commercial and institutional purposes such as restaurants, schools and prisons is fuelwood.

TABLE 1. BASELINE AND ALTERNATIVE SCENARIOS.

BUSINESS MODEL	BASELINE SCENARIO	ALTERNATIVE SCENARIO
Dry fuel manufacturing	- Fuelwood is used as a source of energy for household, institutional and commercial use - Agricultural residues are burnt in open fields during land preparation for planting crops	- Briquetting of agricultural residues - Briquettes are used as a source of energy for institutional and commercial use - Agricultural residues are sourced from farmers spread over a large geographical area
ESCO	- Households derive energy for their lighting needs from kerosene - Electricity supply for commercial centers and other public centers are derived from diesel generators	- Gasification of agricultural residue to generate electricity - Households and commercial users use electricity from gasification processes - Agricultural residues are sourced from farmers spread over a large geographical area
Onsite energy generation	- Fuelwood is used as a source of fuel for cooking/ heating for institutional and commercial purposes - People practice open defecation	- Biogas production from human waste in public toilets - Biogas is used for cooking/heating by institutional and commercial users

3.2 Environmental Impact Assessment of Energy Business Models

A life cycle of emissions of energy sources derived from agricultural residue and fecal sludge was evaluated. The purpose of the environmental assessment was to identify the environmental impact of utilizing agricultural residues and fecal sludge for the production of fuel briquettes, electricity and biogas and to compare the resulting environmental impacts to those of the energy used under the baseline scenario. The functional unit used for quantifying the environmental impacts depends on the business model in question. The functional unit for the briquette model is 1 kg of briquette used for cooking and heating while for the ESCO, the functional unit is 1 KWh of electricity used for lighting, and for the onsite energy generation model, the functional unit is 1 m^3 of biogas. Environmental indicators selected in this study are CO_2, CH_4, N_2O for climate change, and SO_2 and NO_x emissions (Table 2). Gaseous emissions were expressed in CO_2-eq using conversion factors of 1, 21, and 310 for CO_2, CH_4 and N_2O, respectively (IPCC 2001). SO_2 and other particulate matter are associated with acute chronic respiratory and heart diseases and, given their potentially direct effect on human health, gaseous SO_2 emissions are regarded as criteria air pollutants (Burtraw and Szambelan 2009).

3.3 Financial Analysis of Energy Business Models

The financial viability of the business models is analyzed based on Return on Investment (ROI), Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR) valuation criteria. ROI measures per period, the rates of return on money invested in business. There are several ways to determine ROI; however, in this study, ROI is determined by dividing net profit by total investment. NPV is the total sum of the present value of expected future cash flows. Higher ROI and NPV values represent greater economic benefits. IRR is discount rate for which total present value of future cash flows equals cost of investment. BCR is the ratio of the total benefit of a project relative to its costs, both benefits and costs expressed in discounted present values. The following steps were carried out to estimate the valuation criteria:

- Estimate parameters of production and sales for the business model.
- Identify and estimate the capital costs.
- Create cash flow over the useful life of the business.
- Estimate the expected NPV, IRR and BCR.
- Perform a sensitivity analysis.

The analysis is based on data collected from existing businesses in Uganda and on literature. The following

TABLE 2. ENVIRONMENTAL IMPACT CATEGORIES.

ENVIRONMENTAL IMPACT CATEGORIES	ASSESSMENT CRITERIA	UNIT
Climate change	Carbon dioxide (CO_2) Methane (CH_4) Nitrous oxide (N_2O)	kg CO_2-equivalent
Other emissions	Sulfur dioxide (SO_2) Nitrogen oxide (NO_x)	kg SO_2 kg NO_x

sections present key assumptions on the revenue, capital cost, production cost and other factors considered in conducting the financial analyses.

4. DRY FUEL MANUFACTURING BUSINESS MODEL

4.1 Technological Options for Dry Fuel Manufacturing Model

The opportunity to utilize agricultural residues more efficiently, with a reduction in pollution levels has, in recent years, aroused the interest of developing countries in dry fuel manufacturing technologies (Grover and Mishra 1996). Waste processing technologies such as briquetting have the potential to counteract many adverse health and environmental impacts connected with traditional biomass energy. To improve the waste management, reduce the rate of deforestation and increase access to modern energy technologies, recycling agricultural waste to manufacture briquettes is a simple and low-cost technology. Briquettes are densified biomass fuels used for heating in different systems. They are an affordable source of energy and can be used in cooking instead of the traditional charcoal and firewood. The main purpose of briquetting a raw material is to reduce the volume and thereby increase the energy density. This also improves the handling characteristics of the materials for transporting, storing and usage (Grover and Mishra 1996).

4.1.1 Raw Materials Used for Briquette Production

Briquettes can be produced from various raw materials such as agricultural residues, organic municipal solid waste, sawdust from timber mills and other woody biomass. However, the quality of the briquette which is measured by its energy content, depends on the raw materials used. The selection of suitable input materials, in addition to availability, is based on the input's desirable characteristics such as low moisture content (10-15%), low ash content (4%) and uniform or granular flow characteristics of the raw material (Tripathi et al. 1998). The main sources of input for briquette production in Uganda include agricultural residues such as maize cobs, rice husks, coffee husks, groundnut husks, etc., and wood processing waste (such as sawdust). Uganda, where the agriculture sector is a component important to the growth of the economy, generates large quantities of agro-waste as data provided by the government indicated that annual agricultural wastes available come to 1.2 million tons and daily municipal solid waste (MSW) generated in the city of Kampala is estimated to be 1,500 tons (Uganda Renewable Energy Policy 2007). Table 3 shows the characteristics of agricultural residue and the available amount in Uganda.

4.1.2 Human Excreta as Input for Briquette Production

Briquettes can also be produced through the treatment of human excreta such as fecal sludge which is obtained from septic tanks or pit latrines located in or near households, commercial or community toilets as well as sewage sludge from municipal wastewater treatment plants applying biological treatment methods (Supatata et al. 2013). Dry fuel (briquette) production is an attractive option for recycling of fecal sludge besides biogas (Diener et al. 2014). In Kampala with a population of about 1.7 million people, only 7% of the population is served by a centralized sewer system with the rest of the population using public and private pit latrines and septic tanks (Uganda Bureau of Statistics 2006; NWSC 2004). The fecal sludge is discharged at Bugolobi Sewage Treatment Works where it is collected in a large pond to settle before it is finally landfilled (Diener et at. 2014). Various studies have shown that fecal sludge can be processed to yield briquettes with comparable energy content to solid fuels currently in use in developing countries and can potentially become an attractive fuel alternative, with or without charring (Diener et al. 2014; Ward et al. 2014).

TABLE 3. AGRICULTURAL RESIDUES AVAILABLE AND THEIR ASH CONTENT IN UGANDA.

AGRICULTURAL RESIDUE	ASH CONTENT[a] (%)	ANNUAL PRODUCTION ('000 TONS/YEAR)
Bagasse	1.8	590
Rice husks	22.4	25-30
Rice straw	17	45-55
Sunflower hulls	1.9	17
Cotton seed hulls	4.6	50
Tobacco dust	19.1	2-4
Maize cobs	1.2	234
Coffee husks	4.3	160
Groundnut shells	6.0	63

Source: Uganda Renewable Energy Policy 2007; MEMD 2008; [a]Grover and Mishra 1996.

Successful conversion of fecal sludge to briquette, however, requires energy efficient ways to dry and process the sludge due to its high moisture content. Low cost drying methods such as sun drying are preferred (Ward et al. 2014). For example, Pivot Works, a city scale fecal sludge to briquette factory in Kigali, relies on the sun for the key portion of the sludge to fuel conversion process thus lowering capital and production costs. Pivot Works has demonstrated that their city scale sludge to fuel factory produces briquettes with comparable energy content to other solid fuels currently used in the country and that the briquette produced is a cost-competitive fuel that is used by industrial kilns and boilers (http://www.pivotworks.co/pivot-fuel/).

4.1.3 Briquetting Process

The process of making briquettes depends on whether they are carbonized or noncarbonized (Figure 2). Carbonized briquettes are made from raw materials that have been carbonized through partial pyrolysis to produce char which is then compacted into a briquette. Carbonized briquettes are used as a replacement to charcoal for domestic and institutional cooking and heating. The traditional charcoal-making techniques such as carbonization of raw materials using earth pit or steel kilns with conversion efficiencies of less than 10% are the dominant methods of carbonization in developing countries (Ferguson 2012). However some improved processes have been developed for small-scale char production, with improved efficiencies of up to 30% (Ferguson 2012). Eco-Fuel Africa, a carbonized briquette-making enterprise in Uganda, for example, invented a low-cost kiln made out of old oil drums to carbonize its agricultural waste to produce charcoal powder. On the other hand, noncarbonized briquettes are made directly by solidifying/compacting the raw material. They are used by industrial and commercial processes such as manufacturing bricks, producing lime, smoking fish, curing tobacco, brewing beer, and drying coffee and tea, which rely on charcoal and firewood for cooking and heating purposes. They can also be used as a replacement fuel among rural populations where firewood is still dominant (Ferguson 2012).

Preprocessing

Depending on the characteristics of the raw material used and on the type of briquette to be produced, the raw materials need to go through a preprocessing stage before briquetting. This primarily involves shredding of raw materials, sieving, pulverizing and drying. This preprocessing step can be done manually by crushing and chopping or by using mechanized milling machines and can potentially be labor- and energy-intensive depending on the type of raw material used. For example, residues such as rice husks and sawdust require no drying and minimum chopping and crushing to break them down, thus considerably reducing the energy and labor required to prepare the raw materials (Chaney 2010). Thus careful consideration should be taken when selecting appropriate raw materials for briquetting to minimize cost of production.

Binding materials

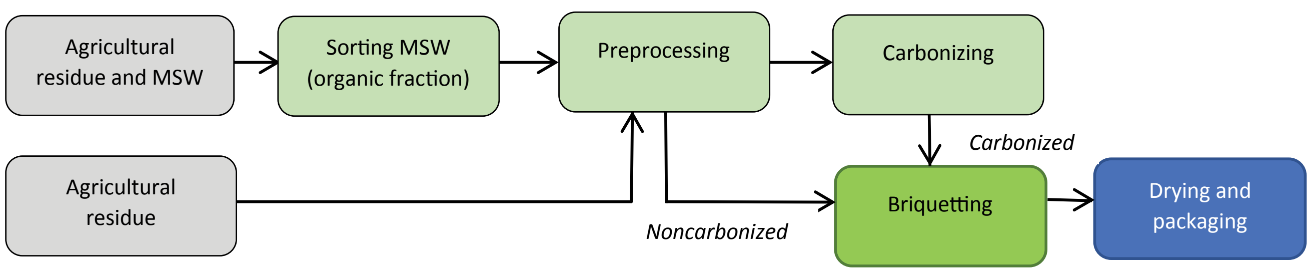
Binding materials are needed in order to ensure that the final product remains in a compact form and has the required strength to be able to withstand handling, transportation and storage. Examples of briquette binders include starch (rice flour, cassava flour, and sweet potato paste), natural resins, tar, molasses, algae and gum Arabic (EEP 2013). Starch is the most commonly used in East Africa. When selecting a binder, careful consideration should be taken to ensure that it is nontoxic for laborers working in briquette making. Furthermore, the effect of the binder on the combustion of briquettes, emissions occurring during burning and the residue after combustion need to be considered when the binding materials are selected.

Briquetting/densification

Briquetting essentially involves two parts; the compaction under pressure of loose material to reduce its volume and to agglomerate the material so that the product remains in the compressed state (http://www.fao.org/docrep/t0275e/t0275e04.htm). There are different methods of briquetting which can be grouped into high, medium and low-pressure compactions. For these methods, a wide range of technologies have been developed. These can be grouped into low-pressure, piston, screw and roller presses (Maninder et al. 2012; FAO 1990). Each of the technologies is described below.

- *Low pressure or manual presses* are simple, low capital-cost options which require low skill levels and no electricity to operate and are used for producing both carbonized and

FIGURE 2. PROCESS DIAGRAM OF BRIQUETTING.



noncarbonized briquettes. These are suitable in areas where there is no access to electricity. A number of manual technologies exist in low-income countries that have been developed as low-cost options, especially in the rural context. However, the briquettes produced through this process may not have the desired quality as they are known to crush easily, particularly when mishandled or exposed to water.

- *Piston presses* are large machines whereby a heavy piston forces biomass material through a tapered die, which compacts the biomass as a result of a reduction of the diameter, using high pressure. Depending on the operating method, piston extruders can produce between 200 and 750 kg of briquettes/hour (Ferguson 2012). Briquettes are extruded as a continuous cylinder. These machines are used to produce noncarbonized briquettes.
- *Screw presses* extrude a briquette through a die and produce briquettes with a homogenous structure which are often cylindrical. They can be operated continuously, which is the main advantage compared to piston extruders. The main disadvantage is the wear of the screw, which needs relatively high investment costs compared to the costs of the extruder itself. Typically, a screw press has the capacity to produce 150 kg of briquettes/hour (Ferguson 2012).
- *Roller presses* are mainly used to produce carbonized briquettes and are also widely applied for the production of charcoal briquettes. Roller presses involve two rollers continuously rotating in the opposite direction, converging at point of compaction where the processed raw materials are transformed into the shape of the desired briquette (EEP 2013). As this technology does not provide enough pressure to compact the raw materials, water and binders such as cassava or wheat flour are added to hold the material together. A roller press has the capacity to produce 1,500 kg of briquettes/hour; this capacity is high compared to that of other briquetting technologies (Ferguson 2012).

4.2 Environmental Impact Assessment of Dry Fuel Manufacturing Model

Total emissions under the baseline scenario represent emissions from burning of agricultural residue in open fields and from combustion of fuelwood in stoves. Total emissions under the briquette business scenario represent emissions from agricultural residue collection and transportation, emissions from briquetting, emissions from transport and combustion of briquettes in institutional stoves. These calculations of the total emissions were based on a number of studies (Hu et al. 2014; Ruiz et al. 2013; Okello et al. 2013; Sparrevik et al. 2012; Young and Khennas 2003; IPCC/OECD 1999).

4.2.1 System Boundary

The system boundary applied in this study contains 1) agricultural residue collection and transportation, 2) residue briquetting, 3) briquette fuel distribution, and 4) briquette fuel combustion in stoves. The environmental impacts at each stage or process are taken into account. For the briquettes produced, we assumed a replacement of fuelwood for use in institutions and commercial sectors for heating and cooking. For the agricultural residue used as input in the briquetting process, we assumed that under the baseline scenario, the residues are burned in open fields during land preparation for planting crops (Okello et al. 2013). Thus, emissions associated with this practice were accounted for when assessing the environmental impacts. The environmental impacts associated with the main agricultural commodity were excluded from the scope of the study. Moreover, emissions associated with machine or equipment used in the briquette business are excluded from the scope of this study.

4.2.2 Agricultural Residue under the Baseline Scenario

Under the baseline scenario, agricultural residues are burned in open fields during land preparation for planting crops. The GHG and other particle emission effects from burning of agricultural residues are estimated based on Sparrevik et al. (2012) (Table 4). The GHG and other emissions avoided as a result of using the agricultural residues are measured in terms of the avoided kg of CO_2 and other pollutants

TABLE 4. EMISSION FACTORS FOR OPEN BURNING OF AGRICULTURAL RESIDUES UNDER THE BASELINE SCENARIO.

EMISSIONS	EMISSION FACTOR (KG EMISSION/KG OF DRY RESIDUE BURNED)
CH_4	0.0012
N_2O	0.00007
SO_2	0.002
NO_x	0.0031
CO	0.0347

Source: Sparrevik et al. 2012.

(SO_2, NO_x, CO) based on agricultural residues used to produce 1 kg of briquettes.

4.2.3 Agricultural Residue Transportation and Briquetting

The agricultural residues used in the briquette making are sourced from farmers who are spread over a large geographical area. It is assumed that during processing, input loss of 8-12% occurs. Assuming a 10% input loss during processing, for a 2,000 ton briquette production, 2,222 tons of input are required. The CO_2 emissions produced at the collection stage and subsequent transportation to the briquette plant are included in the assessment. In general, the level of emissions under the briquette business scenario is expected to be low compared to emissions under the baseline scenario where agricultural residues are burned in the field (Ruiz et al. 2013). The GHG emissions are measured in terms of the kg of CO_2 emitted as a result of collection and transportation, in supplying 1 kg of briquettes. It was assumed that collection of agricultural residues is done within an average distance of 40 km from the processing plant using a truck of 25-ton capacity and an effective load-carrying capacity of 15 tons (Ruiz et al. 2013; Okello et al. 2013). The use of trucks results in CO_2 emissions from the use of diesel fuel. The CO_2 emissions range from 2.6 to 3 kg/liter of diesel fuel (Ruiz et al. 2013). In this study, CO_2 emissions of 3 kg/liter of diesel fuel were used. The CO_2 emissions are calculated based on a mean distance of 40 km and diesel consumption of 0.45 liters/km (Table 5).

At the plant, the agricultural residues are sieved, pulverized, using a hammer mill, and dried to a moisture content of 13% using a flash drier. The agricultural residues are then blended to get a homogeneous mixture of different materials and fed into a briquetting machine to be compacted. According to Hu et al. (2014), energy uses during preprocessing are 3 KWh/ton for drying, 18 KWh/ton for chopping and 13 KWh/ton of briquette. The environmental impacts associated with the energy used during production of briquettes should be taken into account. In this study it is assumed that the source of energy for preprocessing is from hydropower generation stations (which are CO_2 neutral) as Uganda relies on electricity produced from hydropower generation. In contrast, other studies such as that by Hu et al. (2014) have taken into account the environmental impacts associated with electricity used for briquetting as the electricity is supplied by a coal-fired power plant. In Kampala, there are frequent power cuts and business entities have back-up generators which run on diesel fuel. Emissions related to diesel used for generators during power cuts are not accounted for in this study due to lack of sufficient information on the frequency of power cuts and the use of diesel fuel for generators.

4.2.4 Briquette Transportation and Combustion

The same truck with a maximum capacity of 25 tons is assumed to be used to transport the briquettes to end users within an average distance of 20 km. The briquettes are substituted for fuelwood and can be used for cooking without stove modifications. The energy content in 1 kg of briquette and 1 kg of fuelwood is estimated to be 16.8 MJ and 13.8 MJ, respectively (IPCC/OECD 1999; Hu et al. 2014). This implies that 0.82 kg of briquette can replace 1 kg of fuelwood. Other studies have assumed that 1 kg of fuelwood can be replaced by 0.7 kg of briquettes (Young and Khennas 2003). Thus, the use of 1 kg of briquette would conserve 1.22 kg of fuelwood. The combustion efficiency of, and the resulting emissions from, briquettes greatly depend on the combustion equipment used (Roy and Corscadden 2012). The institutional wood stoves used in most East African countries have an efficiency of 45% when wood is used and 50% when wood is replaced by briquettes (Young and Khennas 2003). This nominal increase in efficiency of 5% is because briquettes have a uniform shape and can fit to stoves allowing cooking in enclosed stoves thus increasing efficiency (Young and Khennas 2003). The emissions associated with combustion of fuelwood under the baseline scenario and briquettes under the briquette business scenario are presented in Table 6.

4.2.5 Net Environmental Impact of Dry Fuel Manufacturing Model

The total emissions under the baseline scenario constitute the total emissions associated with fuelwood use and burning of agro-residues in open fields. These are the emissions avoided as a result of utilizing agricultural residue for the production of fuel briquettes thereby replacing fuelwood. The emissions from the briquette business constitute the total of emissions associated with transportation of agro-residues, transportation of briquettes and combustion in stoves.

TABLE 5. CO_2 EMISSIONS FROM TRANSPORTATION OF AGRO-RESIDUES TO THE BRIQUETTE PLANT.

ITEM	UNIT	VALUE	SOURCE
Average return trip distance – agro-waste to briquette plant	km	40	Okello 2014
Distance of average return trip - briquette plant to final users	km	20	Assumed
Capacity of truck agro-waste/load	ton	15	Ruiz et al. 2013
Diesel consumption	liters/km	0.45	Ruiz et al. 2013
CO_2 emission/liter of diesel	kg CO_2/liter	3	Ruiz et al. 2013

TABLE 6. EMISSION FACTORS FROM COMBUSTION OF FIREWOOD AND BRIQUETTE.

EMISSIONS	FUELWOOD USE (KG EMISSION/KG OF FUELWOOD)	BRIQUETTE USE (KG EMISSION/KG OF BRIQUETTE)
CO_2 emission	1.513	0.7604
CH_4 emission	4.14E-03	2.98E-03
N_2O emission	5.52E-05	9.68E-06
SO_2 emission	-	-
NO_x	1.38E-03	4.84E-06
CO	6.9E-02	1.48E-02

Source: IPCC/OECD 1999; Okello 2014.

Emissions under the baseline scenario

The emissions avoided/kg of briquette produced are shown in Table 7. These are emissions under the baseline scenario. The highest contribution to GHG emission savings is from avoided burning of fuelwood. The reduced use of fuelwood also implies that environmental degradation through deforestation is minimized. The overall savings in GHG emissions from avoided use of firewood and burning of agro-wastes are 2.021 kg of CO_2eq/kg of briquette. Considering the other emissions, the highest contribution to reduction of other emissions expressed in kg of SO_2 and NO_x is from avoided burning of agro-residues. Given the assumption made in this study, savings of 0.0022 kg of SO_2, 0.0051 kg of NO_x and 0.1226 kg of CO are avoided/ kg of briquette.

Emissions under briquette scenario

Processing of agro-residues to produce briquettes results in GHG and other criteria emissions. These emissions are from transporting of agro-residues to the plant, briquetting of agro-residues and transporting and combustion of briquettes. The environmental emissions from the production and combustion of 1 kg of briquette fuel are shown in Table 8. The highest contribution to GHG emissions and other criteria emissions is from combustion of briquettes showing total GHG emissions of 0.831 kg CO_2eq, 4.84E-06 kg of NO_x and 1.48E-02 kg of CO/kg of briquettes.

Net emissions

The overall GHG emissions from the production and use of 2,000 tons of briquette fuel obtained from agro-residues

TABLE 7. EMISSION SAVINGS FROM AVOIDED USE OF FIREWOOD AND BURNING AGRO-RESIDUES (KG OF EMISSION/ KG OF BRIQUETTE).

SAVINGS FROM	GHG EMISSIONS	OTHER CRITERIA EMISSIONS		
	CO_2	SO_2	NO_x	CO
Firewood conservation	1.969	0	0.0017	0.0840
Burning agro-residues	0.052	0.0022	0.0034	0.0386
Total savings	2.021	0.0022	0.0051	0.1226

TABLE 8. ENVIRONMENTAL EMISSIONS FROM THE PRODUCTION AND USE OF 1 KG OF BRIQUETTE.

EMISSIONS FROM	GHG EMISSIONS	OTHER CRITERIA EMISSIONS		
	CO_2	SO_2	NO_x	CO
Transportation of agro-residues	0.004	-	-	-
Transportation of briquettes	0.001	-	-	-
Combustion of briquettes	0.826	-	4.84E-06	1.48E-02
Total emissions	0.831	-	4.84E-06	1.48E-02

are shown in Figure 3. GHG emissions from combustion of fuelwood and burning of agro-waste are negative, representing GHG emission savings from the use of briquette. The savings are mainly from avoided fuelwood use. Under the briquette business scenario, the highest GHG impact is from briquette combustion. Other processes such as transport of raw material and briquette did not contribute significantly to the total environmental impacts of the briquette business.

Although the briquette business results in environmental impacts, these impacts are far less than under the baseline scenario. The GHG emission savings are more than the emissions from the briquette business, thus resulting in net GHG emission savings of 1.19 kg CO_2eq/kg of briquette (2,379 tons of CO_2eq/year).

Figure 4 shows other criteria emissions – SO_2, NO_x and CO – under baseline and briquette business scenarios (2,000 tons of briquettes). The untreated or burning of agro-residues under the baseline scenario contributes the highest SO_2 and NO_x emissions. In the briquette scenario the agro-residues are processed to briquette resulting in a lower environmental impact. The highest CO emissions are from fuelwood use. The combustion of briquette also contributes to CO emissions but it has a lesser impact than under the baseline scenario thus resulting in net emission savings. The net emission savings from 2,000 tons of briquette are 4.4 tons of SO_2, 10.24 tons of NO_x and 215 tons of CO/year.

Value of carbon credits and other emissions

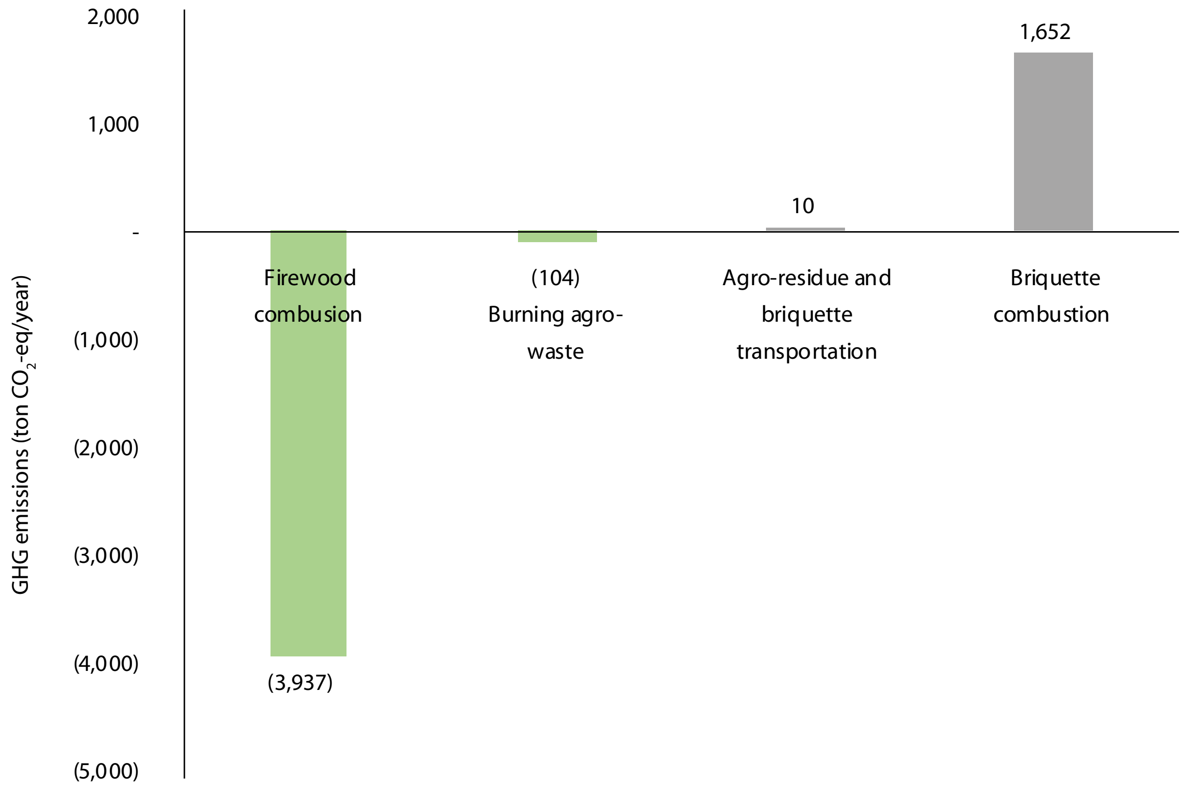
Carbon credits are traded on either the regulatory Clean Development Mechanism (CDM)[1] market or on the voluntary carbon market depending on their eligibility. The Certified Emission Reduction (CER) is the credit generated under CDM while the Voluntary Emission Reduction (VER) is generated under the voluntary carbon market. Since the VER is suited for small-scale projects and is typically sold in volumes that appeal to clients seeking small reductions to offset their footprints, in this study the VER unit is considered. The VER unit is equivalent to a reduction of 1 ton of CO_2 equivalent emissions (Reuster 2010). Based on the World Bank (2014), carbon credit prices in the European Union Emissions Trading System (EU ETS) ranged about USD 5-9 (€4-7) in 2014 while prices were USD 18 (€13) in 2011. In this study it is assumed that carbon credits are worth on average USD 7/ton of CO_2 equivalent (Table 9). However, values of the other emission savings (NO_x and SO_2) were not included in the analysis.

4.3 Social Impacts of Dry Fuel Manufacturing Model

4.3.1 Additional Income for Farmers from the Sale of Agricultural Residue

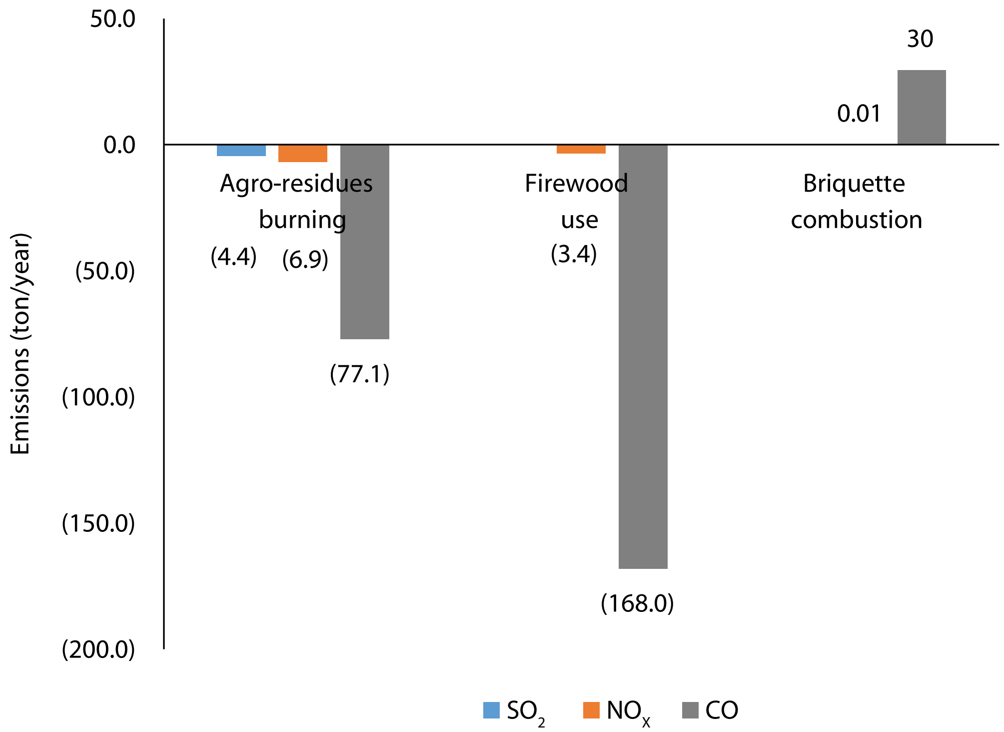
As a predominantly agricultural country, Uganda generates large quantities of agricultural residues. The major agricultural residues include maize cobs, groundnut shells and coffee and rice husks. Data provided by the

FIGURE 3. GHG EMISSIONS AND SAVINGS FROM 2,000 TONS OF BRIQUETTES (TONS OF CO_2EQ/YEAR).



1 The Clean Development Mechanism (CDM) allows a country with an emission-reduction commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. It allows emission reduction projects to generate Certified Emission Reduction (CER) units which may be traded in emissions trading schemes (IPCC 2007).

FIGURE 4. OTHER EMISSION SAVINGS FROM 2,000 TONS OF BRIQUETTES (TONS/YEAR).



government indicated that annual agricultural wastes available is 1.2 million tons (Uganda Renewable Energy Policy 2007; MEMD 2008). While these agricultural residues are important sources of energy, currently they are burned in open fields wasting valuable energy resources and also leading to serious environmental pollution. In areas where there are large agricultural residues, briquetting fuel plants can be established using local agricultural residue as input to their system. This will benefit farmers and local residents. Farmers will benefit from the sale of agricultural residues and thus earning additional income. The cost of the agricultural residues for the briquette plant, based on the existing plant in Kampala, is USD 129/ton; from this amount farmers are directly paid at the rate of USD 3-14/ton indicating that a 2,000-ton briquette plant has the potential to provide annual additional income of USD 6,666-31,108 to farmers. Thus, on average, the briquette plant contributes to providing an additional income to the farmers at the rate of USD 9.44/ton of briquette produced, resulting in an average annual additional income of USD 18,800 from 2,000 tons of briquettes.

In addition to providing additional income to farmers, the briquette plant contributes to creating of employment for the local community. However, the briquette business is likely to also impact the livelihood of charcoal or fuelwood traders. The briquette business has 50 full-time workers earning a total annual salary of USD 39,600.

TABLE 9. ANNUAL VALUE OF GHG EMISSION REDUCTION FROM BRIQUETTE BUSINESS (2,000 TONS).

ITEM	AMOUNT
Total GHG emission savings (tons of CO_2eq)	4,041
Total GHG emissions from briquette business (tons of CO_2eq)	1,662
Net emission savings (tons of CO_2eq/year)	2,379
Price of VER (USD/ton of CO_2eq)	7
Total value of carbon credit (USD/year)	16,655

4.3.2 Savings for End Users

Replacing fuelwood with briquette fuels for cooking has the potential to contribute to reducing the costs incurred by end users for cooking fuel. In this study, end users are institutional and commercial users. Table 10 shows the potential savings for end users from using briquettes. The energy content in 1 kg of briquette is 16.8 MJ while the energy content in 1 kg of fuelwood is 13.8 MJ (IPCC/OECD 1999; Hu et al. 2014). Thus, fewer briquettes by weight are required for the same amount of heat as compared to fuelwood. In addition to the calorific value of the energy sources, the replacement value of briquettes to fuelwood depends on the efficiency of cook stoves used in institutions. Based on calorific value only, the use of 1 kg of briquette would conserve 1.22 kg of fuelwood. Assuming efficiency of stoves of 45 and 50%, respectively, when fuelwood and briquettes are used for cooking, the actual price/MJ of useful energy is USD 0.039 in fuelwood equivalent and USD 0.034 in briquette equivalent. At the current price of fuelwood (USD 0.24/kg), using briquettes priced at USD 0.282/kg has a potential cost saving of 13% as compared to fuelwood used in institutional stoves. The total annual cost savings for end users from utilizing 2,000 tons of briquettes is estimated to be USD 76,664.

4.3.3 Health Impacts

The use of fuelwood and other biomass in stoves with low efficiency and inadequate venting leads to indoor air pollution exposing people working in kitchens to a major public health hazard (Schirnding et al. 2002). Biomass smoke contains a large number of pollutants that pose substantial risks to human health. Harmful pollutants include particulate matter, CO, NO_2 and SO_2 emissions. Exposure to biomass smoke increases the risk of diseases such as chronic bronchitis, chronic obstructive pulmonary diseases and lung cancer (Lim et al. 2013; Schirnding et al. 2002).

Briquettes are direct replacements to fuelwood used in institutions which have a combustion efficiency of 45%. The fact that complete combustion of biomass is not achieved in the institutional cook stoves results in the production of toxic gases such CO and other toxic emissions. The combustion of briquettes in existing institutional stoves will also result in emissions of toxic gases. However, briquettes have advantages over fuelwood as they have low moisture content compared to fuelwood and thus less smoke and toxic emissions are produced during briquette combustion. This will lower gaseous emissions in the kitchen and exposure of people working in kitchens to health hazards.

In addition to health impacts associated with combustion of briquette, health impacts on workers' exposure to emission pollutants during briquette manufacturing should also be taken into consideration. For example, communication with the existing briquette plant in Kampala has revealed that the dust from most of the agricultural residue is hazardous when inhaled by the workers. Thus there is a need to provide workers with protective gears. Health impacts associated with fuelwood and briquette use are not quantified in this study.

4.4 Financial Analysis of Dry Fuel Manufacturing Model

The financial analysis is based on data collected from the existing briquette business in Uganda, a literature review and expert elicitation. The major source of revenue for the briquette business is the sale of briquettes to different clients. Based on existing briquette plants in Uganda and other East African countries, noncarbonized briquettes are primarily targeted for institutional, commercial and industrial fuel use such as prisons, schools, cement factories and brick factories, in smoking fish, curing tobacco, brewing beer, and drying coffee and tea, etc. The selling price of noncarbonized briquettes in Uganda ranges between USD 200 and 400/ton (Ferguson 2012). The price of noncarbonized briquette is assumed to be USD 282/ton (based on Kampala Jellitone Suppliers Ltd., a briquette-making business enterprise in

TABLE 10. SAVINGS TO END USERS FROM USING BRIQUETTES.

Item	Fuelwood	Briquette
Fuelwood replaced by briquettes (tons) (A)	2,435	2,000
Heating value (MJ/kg) (B)	13.8	16.8
Price (USD/ton) (C)	0.24	0.282
Efficiency of stoves (%) (D)	45	50
Actual price/useful energy (USD/MJ) *(E= C/(B*D)*	0.039	0.034
Total energy value of fuelwood replaced (1,000 MJ) *(F=A*B*D)*	15,121	
Savings from briquette use (%) *(G= [E (Fuelwood)-E(Briquette)]/E(Fuelwood)*	13	
Total savings from shifting to briquettes (USD/year) (E*F*G)	76,664	

Uganda). Based on the experience of existing briquette businesses in Uganda, not all of the briquettes produced are sold in the first few years of operation and thus it is assumed that in the first year, 75% of the total briquette production is sold, the second year, 85% and in the third year and the rest of the period, 95%. Another source of revenue for a briquette business is from manufacturing and selling of cooking stoves. However, in this exercise, the sale of stoves is not considered as it is assumed that clients can use noncarbonized fuel briquettes without having to change or modify their existing cooking stoves.

The costs of the briquette business primarily include capital investment and operating costs which include input cost, labor cost, operation and maintenance (O&M) costs, utilities, marketing and packaging costs. The useful life of the briquette plant is assumed to be 15 years. The amount of the capital costs depends on the technologies used during preprocessing of raw materials and on the briquetting technology used and is estimated based on existing plants of similar scale in Uganda. The capital cost includes cost of land, building, machine and equipment, and environmental impact assessment cost which are one-time costs at the beginning of the project's life (Table 11). The area of land required is 2,500 m^2 (based on similar businesses in Kampala). The machine and equipment cost is inclusive of two hammer mills, two briquetting machines, hot-air generator for drying, a generator and other office equipment. The total capital cost is estimated to be USD 292,492. It is assumed that 15% of the capital cost is financed by debt. Interest on borrowed funds is assumed to be 22% (Bank of Uganda).

To produce noncarbonized biomass fuel briquettes, the inputs used are agricultural residues. The collection and transportation of the input are assumed to be outsourced. Table 12 presents the input parameters for the financial analysis. It is assumed that during processing, an input loss of 8-12% occurs. Assuming a 10% input loss during processing, for a 2,000 ton briquette production, 2,222 tons of input are required. Production and other costs are estimated based on existing plants of a similar scale in Uganda.

The cost of input, including transportation cost is assumed to be USD 129/ton. The total number of full-time workers is 50 and total monthly labor cost is USD 3,300. Other costs include marketing and distribution (USD 12/ton), packaging cost (USD 4/ton) and utilities (USD 42/ton). Labor and parts are needed to maintain and operate the briquetting machines and equipment. O&M costs are assumed to be 5% for machine and equipment and 2% for building. A discount rate of 12% is assumed. The selling price of briquette and other input costs are subjected to an escalation of 3%. A straight line method of depreciation is used for depreciable capital costs assuming a useful life of 15 years with a salvage value of 10% of total depreciable cost. The current tax for similar businesses in Uganda is 24% comprising 18% value added tax (VAT) and 6% withholding tax.

The financial analysis of a briquette business is presented in Table 13. Results show that the business model resulted in a positive net profit. In the first year when it is assumed that 75% of production is sold, the net profit is USD 29,173, for the second year when 85% of production is assumed to be sold, net profit increases by 40% and for the rest of the period mean net profit increases as proportion of sales to production increases to 95%. ROI in the first year is 10% and increases to 14% in the second year and to more than 20% for the rest of the period. The payback period is 4 years. Assuming a discount rate of 12% and a useful life of 15 years, the business model resulted in a mean NPV of USD 256,480 and an IRR of 25% indicating that the business model is financially viable.

4.5 Consolidated Socioeconomic Results of the Dry Fuel Manufacturing Model

This section presents the consolidated socioeconomic results of the dry fuel manufacturing business model. The analysis looked at the potential impact of each business model at three levels where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 12% to obtain the present value of social and environmental impacts.

TABLE 11. CAPITAL COST OF BRIQUETTE PLANT (USD).

COST ITEM	AMOUNT
Construction and building	140,000
Machine and equipment	124,492
Cost of environmental impact assessment	5,000
Land	23,250
Total	292,492

TABLE 12. INPUT PARAMETERS FOR FINANCIAL ANALYSIS OF DRY FUEL MANUFACTURING MODEL.

INPUT FACTOR	UNIT	VALUE	SOURCE/REMARK
Capacity of plant	ton	2,000	Assumed
Input loss during processing	%	10%	Expert elicitation
Input cost	USD/ton	129	Based on existing plants in Uganda
Labor cost	USD/month	3,300	Based on existing plants in Uganda
Marketing and distribution	USD/ton	12	Based on existing plants in Uganda
Packaging	USD/ton	4	Based on existing plants in Uganda
Utilities	USD/ton	42	Based on existing plants in Uganda
Discount rate	%	12%	Assumed
Debt repayment period	Year	6	Assumed
Price of briquette	USD/ton	282	Based on existing plants in Uganda
Escalation on selling price of briquette	%	3	Bank of Uganda
Escalation on input and other costs	%	3	Bank of Uganda
O&M cost of machine and equipment	%	5	Assumed
O&M cost of building	%	2	Assumed
Annual write-off from revenue	%	5	Assumed
Depreciation rate	%	6	Assuming a useful life of 15 years, salvage value of 10% using straight line
Tax rate	%	24	Current taxes for similar businesses in Uganda (18% VAT and 6% withholding tax)

TABLE 13. FINANCIAL RESULTS OF BRIQUETTE BUSINESS (USD).

	Year								
	0	1	2	3	4	5	6	7	...
Capital cost	292,742								
Revenue:									
Briquette sales		423,000	493,782	568,430	585,483	603,048	621,139	639,773	...
Costs:									
Input cost		215,000	250,977	280,503	288,918	297,586	306,514	315,709	...
Labor cost		39,600	40,788	42,012	43,272	44,570	45,907	47,284	...
Marketing		18,000	21,012	23,484	24,189	24,914	25,662	26,431	...
Packaging		6,000	7,004	7,828	8,063	8,305	8,554	8,810	...
Utilities		63,000	73,542	82,194	84,660	87,200	89,816	92,510	...
O&M cost		9,025	9,295	9,574	9,861	10,157	10,462	10,776	...
Annual write-off		8,460	9,876	11,369	11,710	12,061	12,423	12,795	...
Depreciation		15,870	15,870	15,870	15,870	15,870	15,870	15,870	...
Total cost		374,954	428,363	472,833	486,542	500,662	515,206	530,186	...
Interest payment		9,660	11,786	12,253	12,356	12,379	12,384	-	...
Profit before tax		38,385	53,633	83,344	86,585	90,006	93,549	109,587	...
Income tax		9,212	12,872	20,002	20,780	21,603	22,452	26,301	
Net profit		29,173	40,761	63,341	65,804	68,405	71,097	83,286	...
Cash flow	(292,742)	45,042	56,631	79,211	81,674	84,274	86,967	99,156	...
ROI		10%	14%	22%	22%	23%	24%	28%	...
NPV		256,480							
IRR		25%							

The consolidated socioeconomic results of the dry fuel manufacturing business are shown in Table 14. The briquette business results in a BCR of 1.98, NPV of USD 256,480 and ROI of 27% when only direct benefits from the briquette production are taken into account. NPV increases by 44% when environmental benefits are taken into account and to more than 400% when the environmental and social impacts are taken into account. Taking all externalities into account ROI is 85% showing a more than 200% increase compared to when only direct benefits are considered. The major contribution to the economic feasibility of the business is from the social benefits. The total value of the social benefits of the business is USD 1.07 million with major benefits coming from the savings in energy costs to end users accounting for 49% of the total value of social benefits. The business model results in social benefits of USD 0.5/kg of briquettes. Thus from a socioeconomic perspective, the dry fuel manufacturing business model is sustainable.

In addition to agricultural residue, food waste and MSW, briquettes can also be produced from human excreta at large scale. For example, Pivot Works, a factory which processes human waste to fuel briquettes in Kigali through the use of low cost options has demonstrated that their system is economically viable for large urban areas of more than 500,000 people. The factory produces briquettes with comparable energy content to other solid fuels currently used in the country and that the briquette produced is a cost-competitive fuel that is used by industrial kilns and boilers (http://www.pivotworks.co/pivot-fuel/). Thus in addition to agro-waste-based briquette production, fecal-sludge-based briquette production at a large scale (city scale) has the potential to result in positive economic returns.

5. ENERGY SERVICE COMPANY (ESCO) MODEL

5.1 Technological Options for the ESCO Model

The provision of reliable, secure and affordable energy services is a key factor in providing basic human needs that improve the quality of life and ensure sustainable development (Amigun et al. 2011). Consequently, initiatives to improve the availability of, and reliable access to, energy for the poorest communities around the globe have been central to developmental efforts. In such instances the use of small-scale sustainable energy sources such as biomass gasification is often preferred over the extension of existing national grid infrastructure, which in most developing countries is already struggling to cope with existing demand (Hazelton et al. 2013).

The greater part of the population in Uganda are rural dwellers with 84% of the population living in rural communities; however, the connection to the national electricity grid is centered on the major cities leaving only 1% of the national electricity grid available to the rural dwellers (Buchholz and Volk 2012). Most Ugandans rely on traditional biomass for energy and about 90% of the total energy needs of Ugandans are supplied by fuelwood (Bingh 2004). In order to reduce the overdependence on the already overstretched energy infrastructure, Uganda's decentralized energy sources

TABLE 14. NET SOCIOECONOMIC RESULTS OF DRY FUEL MANUFACTURING BUSINESS.

SOCIOECONOMIC RESULT (USD)	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	SOCIAL, ENVIRONMENTAL AND FINANCIAL VALUE
Financial result:			
NPV	256,480	256,480	256,480
Environmental benefit:			
Value of net GHG emission saving		113,434	113,434
Social benefit:			
Savings in energy costs for end-users			522,719
Additional income to farmers			128,650
Value of employment			269,710
Government tax revenue			149,026
BCR	1.98	2.37	6.02
NPV	256,480	369,915	1,440,019
ROI (average)	27%	33%	85%

are being encouraged to include the use of local biomass resources in energy generation forming the focus of the country's renewable energy policy. It is a generally held view that small-scale, decentralized, wood and other biopower systems based on agro-waste could be more efficient in meeting the energy needs of rural households as well as enabling the achievement of their development objective. This therefore makes such systems a potentially viable alternative off-grid electricity and energy solution to rural Ugandans.

5.1.1 Raw Materials Used for Gasification

The main energy source in Uganda is biomass contributing over 90% of the energy requirements of the country (MEMD 2008). Agricultural production is a predominant economic activity in Uganda, generating large amounts of crop residues every year (Table 3). The most common method of disposal of these crop and other biomass residues in cultivated fields is by burning during land preparation for the next planting season. Residues from agricultural processing facilities are also challenging to dispose of due to costs incurred in their disposal. Even though these residues can be used in the production of energy, presenting a more environmentally friendly way of their disposal, their use as an energy source is limited in Uganda (Okello et al. 2013).

5.1.2 Gasification Process

Biomass gasification enables the conversion of biomass waste including agricultural residues into producer gas, which can then be burned in simple or combined-cycle gas turbines to produce energy or electricity (IRENA 2012). Two types of biomass conversion technologies can be identified generally, i.e., gasification and combustion. Gasification is undertaken using gasifiers which can be either fluidized or using fixed bed gasifiers. The resulting gas is a mixture of carbon monoxide, water, CO_2, char, tar and hydrogen, which can be used in combustion engines to produce energy (IRENA 2012). In most cases, the particular form of the gasifier adopted depends on the capacity of the installation, the quality of the available feedstock, the quality of gas required and environmental pollution standards (Tennigkeit et al. 2006).

Fluidized bed gasifiers

For small- to medium-sized capacity installations, the fluidized bed gasifiers are not deemed suitable due to the large amount of wastewater discharged and the associated environmental challenges coupled with their complicated O&M systems. These gasifiers can however accommodate a different range of feedstock.

Fixed bed gasifiers

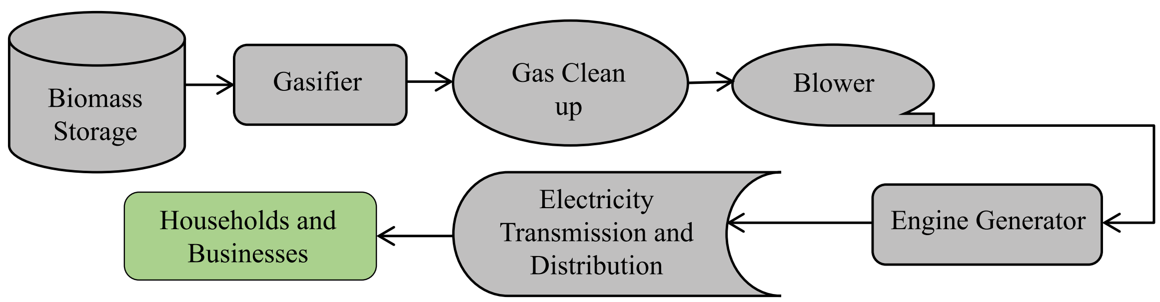
These gasifiers are characterized by high electric efficiency even on a small scale and have the potential of using the waste heat from the system. There are two main types of fixed bed gasifiers, the Up-draught and the Down-draught gasifiers.

- *Up-draught gasifiers* present the simplest technical solution and show high efficiencies but they produce high amounts of tar and hence are not well suited for production of electricity.
- *Down-draught gasifiers* have a lower gasification efficiency but produce gas with a low tar content suitable for engines. As a downside they have more strict requirements on the feedstock resulting in more demanding logistics. This gasifier has been widely used for rural electrification in India and Thailand using agricultural residues as feedstock.

The electricity generation system consists of a gasifier, filters and a gas engine connected to a generator. The gasifier is a down-draft type, where the feedstock is loaded from the top into the hopper through to the combustion chamber. Air is drawn through the top, and partial combustion occurs under a restricted supply of oxygen to give producer gas, which comprises hydrogen, carbon monoxide and methane. The residual char drops to the bottom of the chamber and is subsequently removed. The gas that is generated is water-cooled and cleaned through a series of filters made of char and finally a cloth filter to eliminate particulate matter. The gas is then burned in an engine connected to a generator which generates electricity.

Tar and ash are removed during shut downs and at regular schedules from the cooling and cleaning units of the gasifier system as they adversely affect the performance of the engine. In the producer gas mode of operation, appropriate provision is made for initiating combustion, which can completely eliminate dependence on diesel, especially in remote locations, where transportation of diesel itself may be a difficult task (Nouni et al. 2007). The electricity generated is then distributed to various households and other commercial consumers through a locally established grid (Figure 5).

FIGURE 5. PROCESS DIAGRAM OF GASIFICATION.



5.2 Environmental Impact Assessment of the ESCO Model

The environmental impact assessment of a 120 KW capacity biomass gasification plant is carried out to identify the impact on the environment of using agricultural residues for electricity generation and also to compare these impacts with those created through the existing mode of disposal of these agricultural residues. The climate change mitigation benefits of the agricultural residue gasification system are assessed based on the findings of a number of life cycle assessment studies (Shafie et al. 2014; Ruiz et al. 2013; Zanchi et al. 2013).

5.2.1 System Boundary

The system boundary for the ESCO model starts with agricultural residue collection and transportation and ends with the electricity-generation process. The environmental impact at each stage is accounted for by calculating the GHG and other criteria emissions. The energy used and the environmental impacts associated with the main agricultural crop production and equipment employed in the gasification process are not within the scope of this study.

5.2.2 Source of Energy for End Users under the Baseline Scenario

Under the baseline scenario it is assumed that households derive energy for their lighting needs from kerosene. Electricity supply for commercial centers and other public centers is derived from fossil fuel (diesel generators). The environmental emissions associated with the use of kerosene lamps by households and diesel generators are shown in Table 15.

5.2.3 Agricultural Residue under the Baseline Scenario

Agricultural residues such as corncobs are burned in open fields after processing of the harvest by removing the seed from the cobs. The GHG and other emission effects from open burning were estimated based on Shafie et al. 2014 and Sparrevik et al. 2012 (Table 16).

TABLE 15. GHG EMISSIONS ASSOCIATED WITH KEROSENE USE AND DIESEL GENERATORS UNDER BASELINE SCENARIO.

SOURCE OF EMISSIONS	UNIT	VALUE
Kerosene:		
CO_2 emissions	kg CO_2/liter	2.520
CH_4 emissions	kg CH_4/liter	0.00035
N_2O emissions	kg N_2O/liter	0.000021
Diesel generators:		
GHG emissions		
(CO_2 and CH_4)	kg CO_2-eq/KWh	1.227

Source: Zanchi et al. 2013; World Resource Institute http://www.ghgprotocol.org/calculation-tools/all-tools

TABLE 16. EMISSION FACTORS FOR OPEN BURNING OF AGRICULTURAL RESIDUE UNDER THE BASELINE SCENARIO.

EMISSIONS	EMISSION FACTOR (KG EMISSION/KG OF DRY RESIDUE BURNED)
CH_4	0.0012
N_2O	0.00007
SO_2	0.002
NO_x	0.0031
CO	0.0347

Source: Sparrevik et al. 2012.

5.2.4 Transportation and Gasification of Agricultural Residue

The agricultural residue to be used in the biomass gasification process consists of corncobs sourced from maize farmers spread across the communities. For a 120-KW capacity plant, altogether 792 tons of biomass are required. The GHG emissions are calculated in terms of CO_2-equivalent of all emissions as a result of collection of agro-residues and transportation to the gasifier/KWh of electricity generated. Emissions associated with transportation of agro-residues are calculated assuming a maximum distance of 30 km radius from the gasifier to the various collection points using a truck with a load capacity of 25 tons. The effective load carried on each trip is 15 tons (Ruiz et al. 2013). The use of the truck results in CO_2 emissions from the use of fossil fuels (Ruiz et al. 2013). Following Ruiz et al. (2013) this study assumes CO_2 emissions of 3 kg/liter of diesel used on the average distance of 30 km and mean diesel consumption of 0.45 liters/km. Table 17 shows the parameters and assumptions made in the residue transportation model.

5.2.5 Net Environmental Impact of the ESCO Model

The emissions under the baseline scenario are the emissions avoided as a result of utilizing agricultural residue for electricity generation thereby replacing kerosene used by households and diesel generators by non-household users. The emissions from the business are the total of emissions associated with transportation and emission of agro-residues during the gasification process.

TABLE 17. CO_2 EMISSIONS FROM THE GASIFICATION PLANT (TRANSPORTATION OF AGRO-WASTE AND GASIFICATION).

TRANSPORTATION PARAMETER	UNIT	VALUE	REFERENCE
Distance of the return trip from the agro-waste to the gasifier	km	30	Ruiz et al. 2013
Capacity of truck for transporting agro-waste	kg	25,000	Ruiz et al. 2013
Maximum biomass weight - based on truck capacity	kg	15,000	Ruiz et al. 2013
Diesel consumption rate of truck	liters/km	0.45	Ruiz et al. 2013
Number of trips/year	#	53	Calculated
CO_2 emission/liter of diesel	Kg CO_2/liter	3	Ruiz et al. 2013
CO_2 emissions-gasification	kgCO_2eq/KWh	0.612	Zanchi et al. 2013

Emissions under the baseline scenario

Under the baseline scenario the total emissions are those attributed to emissions from open burning of agro-residues, emissions from the use of kerosene lamps for lighting by households and emissions from the use of diesel generators. The sum of all these emission levels gives the total avoided emissions due to electricity use from the ESCO model. The business model also results in environmental emissions which are generated from the transportation of feedstock and the gasification process itself. Total GHG emission savings constitute the difference between total avoided emissions and total emissions from the gasification process. Table 18 shows the emissions avoided as a result of electricity from the gasification of agro-residues. GHG emissions avoided/unit of electricity generated come to 0.606 kg CO_2-equivalent/KWh. Avoided emissions from diesel generators and kerosene use are the most significant sources of saving in GHG emissions. Savings from avoided open burning of agro-residues accounted for 16% of the total savings in GHG emissions. Considering other emissions, most emission savings originate from avoided burning of agro-residues in the open field.

TABLE 18. EMISSION SAVINGS/KWH OF ELECTRICITY GENERATED BY THE ESCO MODEL (KG/KWH).

SAVINGS FROM	GHG EMISSIONS	OTHER CRITERIA EMISSIONS		
	CO_2	SO_2	NO_x	CO
Burning of agro-residues	0.094	0.0038	0.0059	0.0347
Diesel generators	0.187	-	-	-
Use of kerosene	0.326	-	-	-
Total savings	0.606	0.0038	0.0059	0.0347

Emissions under the ESCO model

The gasification of agricultural residue to generate electricity is not without emission of GHGs. These emissions are from transportation of agro-residues to the gasification plant and emissions from the gasifier. Table 19 shows GHG emissions from the business model in CO_2-equivalent. The highest contribution to GHG emissions is from the gasification process. The GHG emissions/unit of electricity generated is 0.618 kg CO_2-equivalent.

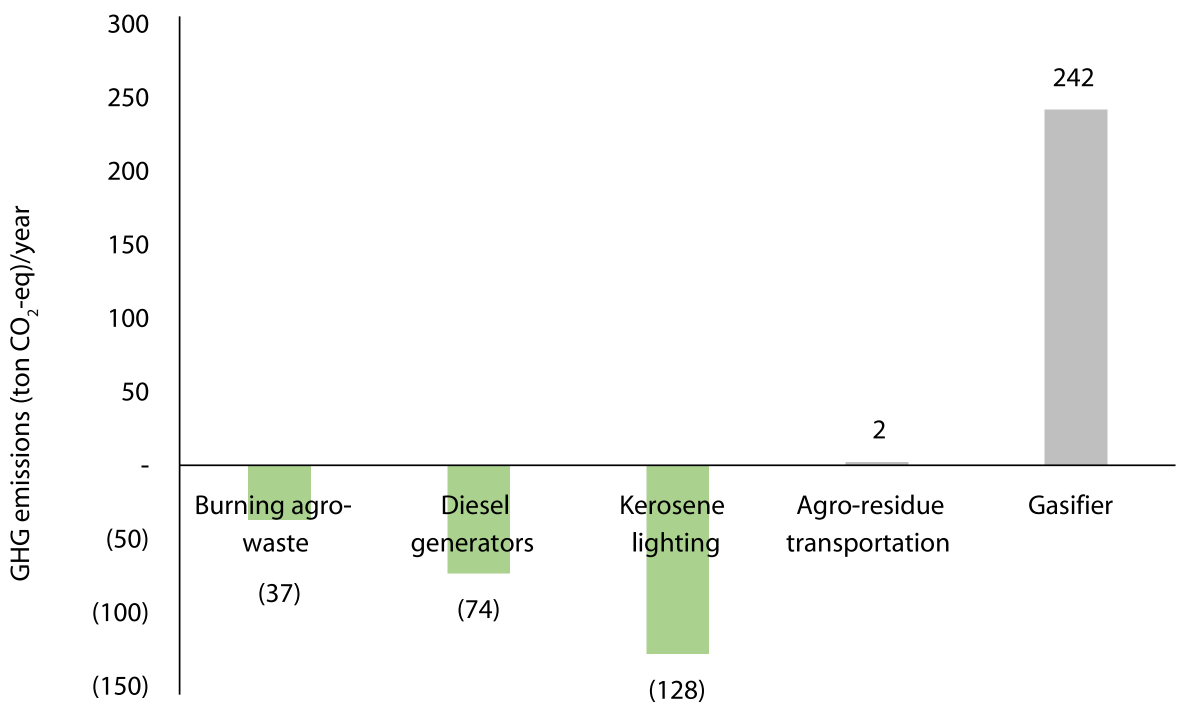
Net emissions

Given the assumptions made and the systems boundary in this study, the process of gasification results in slightly higher GHG emissions in terms of CO_2 equivalent/KWh of electricity compared to the emissions under the baseline scenario. The net GHG emission from implementing an ESCO model is 0.012 kg CO_2-equivalent/KWh. The overall net GHG emissions from a biomass gasification plant with a 120-KW capacity are shown in Figure 6. GHG emissions associated with burning of agro-waste, and the use of diesel generator and kerosene lamps for lighting for households are negative representing the GHG emissions avoided as a result of using electricity generated from gasification of agro-waste. For a 120 KW capacity plant altogether 792 tons of biomass are required and the emissions associated with this amount of agro-waste are 37 tons of CO_2-eq assuming a GHG emission saving of 0.047 kg CO_2-eq/kg of burned agro-residues (Table 16) or 0.094 kg CO_2-eq/KWh. The highest savings in GHG emissions are mainly from avoided use of kerosene lighting by household and diesel generators by non-household users while the highest emissions from the business model are from the gasifier. The GHG emissions from the gasification are slightly more than the emissions avoided under the baseline scenario, thus resulting in a net GHG emission of 5 tons of CO_2-eq/year.

TABLE 19. GHG EMISSIONS/KWH OF ELECTRICITY GENERATED UNDER THE ESCO MODEL (KG CO_2-EQ/KWH).

EMISSIONS FROM	GHG EMISSIONS CO_2
Transportation of agro-residues	0.0054
Gasification process	0.6123
Total emissions	0.618

FIGURE 6. GHG EMISSIONS AND SAVINGS FROM A 120 KW CAPACITY GASIFICATION PLANT (TONS CO_2-EQ/YEAR).



Value of carbon credits and other emissions

It is assumed that carbon credits will be traded in VER units as this is suited for small-scale projects and as VER units are sold in volumes that are targeted to clients seeking small reductions to offset their footprints. The VER unit is equivalent to a reduction of 1 ton of CO_2 equivalent emissions (Reuster 2010). Assuming that, on average, carbon credits are worth USD 7/ton of CO_2 equivalent, the total annual value of carbon credit is USD 133 (Table 20). It should be noted that since the ESCO model resulted in net additional emissions compared to the baseline scenario, the value of carbon credit should be understood as a cost and not as a saving for the ESCO model.

The values of the other emission savings (NO_x and SO_2) were not included in the analysis.

5.3 Social Impacts of the ESCO Model

5.3.1 Savings for End Users

Using electricity from the gasifier in place of other sources of lighting such as candles and kerosene lamps can contribute to expenditure savings for end users. In this study, two categories of end users were considered, i.e., households and commercial/ institutional users. The gasifier has a capacity of 120 KW equivalent to a total of 418,176/KWh electricity. Assuming an energy efficiency of 88% and captive power of 12%, the net available electricity is 367,994 KWh which amount of energy is just enough to serve three adjoining communities. It is assumed that each community has an average of 8 persons/household and 250 households in each community with an electricity need of 30 KWh/month. The electricity need for public centers such as schools and health posts in each community is estimated at 5,000 KWh/year and commercial centers such as grain mills, barber shops, metal workshops, cell phone chargers and other commercial users need an estimated 15,000 KWh/year (Buchholz and Da Silva 2010). Thus each community has an average electricity requirement of 110,000 KWh/ year. Table 21 provides information on the price and the assumptions made in the estimation of expenditure saving for the avoided use of kerosene and candles by households and the expenditure savings by the public and commercial centers by switching from diesel generators to electricity from the gasifier.

TABLE 20. ANNUAL VALUE OF GHG EMISSION REDUCTION FROM THE ESCO MODEL (120 KW).

ITEM	AMOUNT
Total GHG emission savings (tons of CO_2eq)	239
Total GHG emissions from the ESCO model (tons of CO_2-eq)	243
Net emission from the ESCO model (tons of CO_2eq/year)	5
Price of VER (USD/ton CO_2eq)	7
Total value of carbon credit (USD/year)	(35)

TABLE 21. GENERAL INFORMATION ON ALTERNATIVE ENERGY USE.

	UNIT	VALUE	REFERENCE
Household average weekly consumption:			
Candles	#/week	6	GIZ 2011
Kerosene	liter/week	1.3	GIZ 2011
Unit price of candles	USD/candle	0.10	GIZ 2011
Unit price of kerosene (based on weekly expenditure on kerosene of USD1.04)	USD/liter	0.8	GIZ 2011
Unit cost of electricity-diesel generators	USD/KWh	0.25	Buchholz and Voltz 2007
Unit price of diesel	USD/liter	1.21	http://www.globalpetrolprices.com/Uganda/dieselprices/

Replacing kerosene lamps or diesel generators with electricity for lighting and other purposes has the potential to reduce the expenditures incurred by households and other end users. Table 22 shows the potential savings for end users from using electricity generated from gasification of agro-residues. The use of electricity from the gasifier for lighting instead of using kerosene lamps and candles will generate total expenditure savings of USD 4,526/year, i.e., households save USD 0.017/KWh of electricity used. For non-household users of electricity, net expenditure savings of USD 0.03/KWh of electricity used are attained.

TABLE 22. SAVINGS IN ENERGY COSTS FOR END USERS FROM USING ELECTRICITY FROM ESCO (USD/YEAR).

ITEM	VALUE
Savings in energy costs for households:	
Kerosene expenditure avoided	40,411
Candle expenditure avoided	23,515
Gross savings for households	63,926
Expenditure on electricity from ESCO model	59,400
Net expenditure savings by households	4,526
Net savings/unit of electricity used (USD/KWh)	0.017
Savings in energy costs for non-households:	
Diesel expenditure avoided	15,000
Expenditure on electricity from ESCO model	13,200
Net savings in energy expenditure	1,800
Net savings/unit of electricity (USD/KWh)	0.03
Net savings (household and non-household)	6,326

5.3.2. Additional Income to Farmers and Job Creation

The gasification plant contributes to improving the local economy through job creation and providing an additional income to farmers. Corncobs are considered as agricultural waste and are currently burned in open fields. However, in order to have a sustainable supply of feedstock for the gasification plant, it requires the setting up of linkages and, if possible, purchase deals with both small- and large-scale farmers. This provides an extra revenue stream to local farmers. The value of additional income to farmers from the gasification plant is USD 11,832/year assuming the price paid to farmers for using agro-waste for the gasification process ranges from USD 3 to 14/ton. On average, the gasification plant contributes to providing an additional income of USD 0.03/KWh of electricity generated to the farmer. Moreover, the gasification plant contributes to job creation for the local community. The plant employs about seven workers comprising an engineer earning USD 1,130/month, a supervisor earning USD 150/month and five laborers earning USD 65/month. The total annual value of jobs created is USD 19,260. In addition to providing an additional income and job creation, the plant is likely to have indirect impacts on the local economy as new businesses might thrive due to the availability of electricity generated by the gasification plant. Indirect impacts to the local economy are not accounted for in this study.

5.3.3 Health Impacts

The most commonly documented health impacts of kerosene are poisoning, fires and explosions. However, kerosene when lighted emits substantial amounts of fine particulate matter (PM), e.g., carbon monoxide (CO), nitric oxides (NO_x) and sulfur dioxide (SO_2) that are linked to impairing lung functions, increasing infectious illnesses (including tuberculosis), and causing asthmatic and cancer risks (Lam et al. 2012; World Bank 2008). Thus the replacement of kerosene lamps and candles with electric lights will improve indoor air quality and the health conditions of its user. A liter of kerosene when burned emits PM 51 micrograms/hour (mcg/hr), which is above the World Health Organization's 24 hour mean standard of 50 mcg/m^3. This increases the risk of respiratory sickness from exposure to these pollutants. The health benefit from the replacement of kerosene lamps is quantified in terms of lost adult work days (3 days/year), under 5-year old mortality rate (2.2/1,000) and hazard ratio (3.5), i.e., the relative probability of the exposed versus the unexposed being sick, all of which translate into a health benefit of USD 2.5/household (World Bank 2008). Total health expenditure savings from avoiding the use of kerosene lamps is USD 1,875/year.

5.4 Financial Analysis of the ESCO Model

The primary source of revenue for an ESCO model is the sale of electricity to households and other commercial or public centers such as schools, health centers, food conservation, metal workshops and other commercial activities in the community. Electricity generation depends on the number of operating hours of the gasifier. This is assumed to range from 8 to 17 hours based on Buchholz and Volk (2007). Total electricity generation is 347,086 KWh. In this analysis, it is assumed that three communities with an average number of households of 250 each are served by the plant. Household annual electricity demand is assumed to be 270,000 KWh/year. Furthermore, commercial activities are assumed to use the remaining 77,086 KWh/year of electricity. The selling price for electricity generated from a gasifier is assumed to range from USD 0.22 to 0.33/KWh with the minimum price being the price of electricity derived from subsidized diesel generators in Uganda (Buchholz and Volk 2007). Electricity generated from biomass sources can also be connected to the national electrification grid where its price is determined by a feed-in tariff of USD 0.103/KWh (ERA 2012). A byproduct of the gasification process, biochar also provides a minor alternative revenue source to the business. The price of biochar ranges from USD 5 to 6/ton in most eastern African countries and is assumed to be USD 5/ton for Uganda. Biochar sales are targeted mainly at farmers for use as soil additive to improve the properties of soil.

The total capital cost is estimated at USD 345,940 which includes capital cost for the gasifier, land cost, construction and civil works, capital cost of one truck, and capital cost for a household connection (Table 23). The capital cost for the gasifier plant/installed capacity ranges from 2,010 to 2,890 USD/KW with a mean value of 2,087 USD/KW installed capacity (Buchholz and Da Silva 2010; IFAD 2010; Buchholz and Volk 2007). The investment includes a feasibility study, a starter generator (30 KW), supporting infrastructure (including a water pond), gasifier, syngas engine, shipping, duty, insurance, clearance, feedstock processor, feedstock processing shed, installation and commissioning, additional electrical controls and training units (Buchholz and Volk 2007). The household connection cost is assumed to be 60 USD/household with 250 households/community (Buchholz and Da Silva 2010). It is assumed that 30% of the investment cost will be borrowed from local banks at an interest rate of 22% (Bank of Uganda) which will be paid back over a period of 7 years.

TABLE 23. CAPITAL COSTS FOR GASIFIER SYSTEM.

CAPITAL COST ITEMS	VALUE (USD)
Building/civil works	30,000
Gasifier plant	250,440
Capital cost of truck	20,000
Land	500
Capital cost for household connection	45,000
Total investment cost	345,940

Table 24 presents other input parameters used in the model. It is assumed that 100 KW of energy can be derived from the 120 KW capacity gasifier of which 12% is used as captive power for running the gasifier system (IFAD 2010). A straight line method of depreciation is used assuming a useful life of 13 years with a salvage value of 10% of total depreciable cost. The current tax rate for businesses in Uganda is 30%.

The financial analysis of the ESCO model is presented in Table 25. Results show that the business model resulted in a positive net profit. However, at a discount rate of 12%, the business resulted in a negative NPV due to high investment cost and low electricity prices. This implies that returns from the business are not high enough to recover all costs.

TABLE 24. INPUT PARAMETERS FOR FINANCIAL ANALYSIS OF THE ESCO MODEL.

INPUT FACTOR	UNIT	VALUE	SOURCE
Capacity of plant	KW	120	Assumed
Investment cost for gasifier	USD/KW	2,085	Buhholz et al. 2012
Investment cost for grid connection	USD	45,000	Based on estimates by Buchholz and Da Silva 2010
Biomass consumption	tons/year	792	Ankur Scientific India
Net electricity output	KWh/year	347,086	Calculated
Selling price of electricity	USD/KWh	0.22-0.33	Buchholz and Volk 2007
Selling price of biochar	USD/ton	5	Assumed, based on existing prices in East Africa (Rwanda)
Energy conversion efficiency	%	83	Assumed
Captive power used by plant	%	12	Assumed
Feedstock cost and transportation	USD/ton	14	Assumed, based on existing wood gasifier plant of similar capacity in Uganda
Discount rate	%	12	Assumed
Debt repayment period	Year	7	Assumed
Escalation on all prices	%	3	Bank of Uganda
Depreciation rate	%	6	Assumed, useful life of 13 years, salvage value of 10% using straight line method
Tax rate	%	24	Tax rate in Uganda for similar businesses

TABLE 25. FINANCIAL RESULTS OF THE ESCO MODEL (USD).

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	-
Capital cost	*345,940*							-
Revenues:								
Electricity sold (KWh)		347,086	347,086	347,086	347,086	347,086	347,086	-
Sales from electricity		76,359	78,650	81,009	83,439	85,943	88,521	-
Sales from biochar		1,230	1,267	1,305	1,344	1,384	1,426	-
Total revenues		77,589	79,917	82,314	84,784	87,327	89,947	-
Production and other costs:								
Input cost		11,088	11,421	11,763	12,116	12,480	12,854	-
Labor cost		19,260	19,838	20,433	21,046	21,677	22,328	-
O&M cost		15,022	15,473	15,937	16,415	16,907	17,415	-
Annual write-off		2,328	2,397	2,469	2,544	2,620	2,698	-
Depreciation		20,726	20,726	20,726	20,726	20,726	20,726	-
Total cost		68,424	69,855	71,329	72,847	74,411	76,021	-
Profit before tax:		9,165	10,062	10,985	11,937	12,916	13,926	-
Income tax		2,200	2,415	2,636	2,865	3,100	3,342	-
Net profit		9,695	7,647	8,349	9,072	9,817	10,584	-
Cash flow	-345,940	27,692	28,373	29,075	29,798	30,543	31,310	-
ROI		2%	2%	2%	3%	3%	3%	-
NPV	(130,823)							
IRR	3%							

5.5 Consolidated Socioeconomic Results of the ESCO Model

The consolidated socioeconomic results are presented in Table 26. The ESCO model, when only the direct benefits are accounted for, results in negative NPV and BCR of less than 1 implying that the business model is not financially feasible. The performance of the business model barely changes when environmental costs and benefits are taken into account. The business model resulted in higher environmental costs compared to the costs under the baseline scenario. However, the net incremental costs from the environmental impacts are not high enough to bring a change in the performance of the business model. The business model becomes economically feasible when social benefits and costs are included in the analysis. When all externalities are considered the NVP is USD 0.138 million and the BCR is 1.35. Thus, the major contribution to the economic feasibility of the business is from the social benefits. The total value of the social benefits of the business is USD 0.268 million with major benefits coming from the additional income to farmers and jobs created for the local community which accounted for 73% of the total value of social benefits. Thus exclusion of economic and, especially, social benefits could lead to erroneous investment decisions with potentially many investment projects being ignored.

TABLE 26. NET SOCIOECONOMIC RESULTS OF THE ESCO MODEL.

SOCIOECONOMIC RESULT (USD)	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	SOCIAL, ENVIRONMENTAL AND FINANCIAL VALUE
Financial result:			
NPV	(130,823)	(130,823)	(130,823)
Environmental benefit:			
Value of net GHG emission saving		(201)	(201)
Social benefit:			
Savings in energy costs for end users			40,637
Additional income to farmers and jobs created			194,942
Savings in health expenditure for households			12,044
Government tax revenue			20,931
BCR	0.58	0.58	1.35
NPV	(130,823)	(131,024)	137,530
ROI (average)	3%	3%	14%

6. ONSITE ENERGY GENERATION MODEL

6.1 Technological Options for the Onsite Energy Generation Model

During the past decade a number of business-oriented solutions (business models) to sanitation have been implemented in various developing countries to address the sanitation and liquid and solid waste management challenges. In Kenya, the Athi Water Service Board (AWSB)[2] has developed and implemented projects aimed at improving access to safe water and sanitation for the informal settlements by building toilet facilities with biogas systems. Such facilities are also referred to as *Bio-centers* (AFD and AWSB 2010). These bio-centers provide not only toilet services but also cooking services to different users by using the biogas generated from bio-digesters fed with fecal sludge from the toilet facilities. A number of biogas systems have also been constructed in institutions such as schools, hospitals, prisons and other institutions in Rwanda, Nepal and the Philippines. The institutional biogas systems, in addition to improving waste management, are primarily applied to save on fuelwood energy used for cooking.

The onsite energy generation model has sanitation facilities and a bio-digester. The technology applied to convert human waste into biogas is anaerobic digestion. Biogas is "a gas mixture comprising around 60% methane and 40% carbon dioxide formed when organic materials are broken down by microbiological activity in the absence of air" (Bates 2007).

[2] Athi Water Service Board is one of the eight Water Boards under the Ministry of Environment, Water and Natural Resources created to bring about efficiency, economy and sustainability in the provision of water and sewerage services in Kenya.

The biogas can be used for cooking, lighting or heating. The bio-digester is fed with the fecal sludge (FS) from the sanitation facilities equipped with flush toilets (Figure 7).

Various types of organic waste can be used to produce biogas. Table 27 presents biogas yields of different types of organic waste (mainly dung). The hydraulic retention time (HRT) ranges from 15 to 25 days depending on the climatic conditions. Average HRT is 20 days at an ambient average temperature of 25 °C. In addition to biogas, the bio-digester unit produces a digested slurry that can be used as liquid fertilizer.

There are different types of biogas systems in use in developing countries. The two basic designs are fixed dome type and floating drum which are commonly found in Asian countries such as China, India and Vietnam.

FIGURE 7. SCHEMATIC OF THE ONSITE ENERGY GENERATION BUSINESS MODEL.

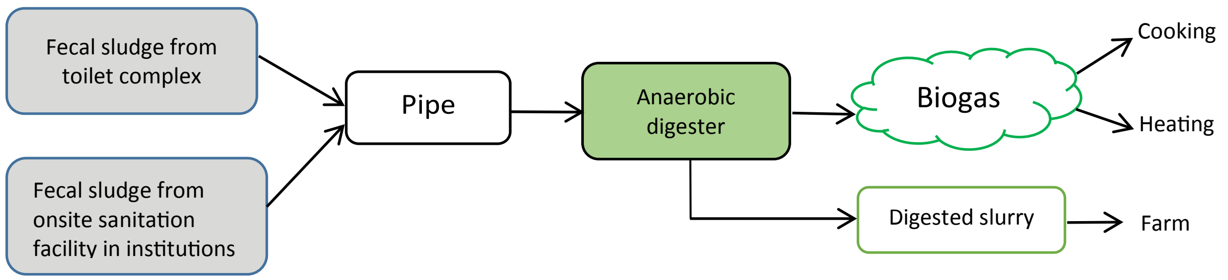


TABLE 27. GAS YIELD POTENTIAL OF HUMAN AND LIVESTOCK WASTE.

INPUT	BIOGAS YIELD (M^3/KG)
Human waste	0.02 - 0.028
Cattle dung	0.023 - 0.04
Pig manure	0.04 - 0.059
Poultry manure	0.065 - 0.116

Source: Updated Guidebook on Biogas Development cited by Buxton and Reed 2010.

6.1.1 Fixed Dome Model

A fixed dome digester consists of an underground brick masonry compartment (fermentation chamber) with a dome on top for gas storage. The digester and the gas holder are integrated parts of the brick masonry structure and the gas pipe is fitted on the crown of the masonry dome (Singh and Sooch 2004).

6.1.2 Floating Drum

This model consists of a cylindrical digester and floating gas-holder or drum (Singh and Sooch 2004). This drum can move up and down depending on the amount of gas in the digester. If biogas is produced, the drum is pushed up and when the gas is used up, the drum sinks providing a useful visual indicator of the amount of the available gas (Buxton and Reed 2010).

6.2 Environmental Impact Assessment of the Onsite Energy Generation Model

The environmental impact assessment of a public toilet complex with a biogas volume of 54 m^3/plant is carried out to identify the impact on the environment of using human excreta to produce biogas for institutional heating or cooking and also to compare these impacts with those created through the existing mode of disposal of human excreta. The public toilet with a biogas plant has the potential to mitigate the GHG and other emissions through the i) avoided emissions from open defecation, and ii) replacing fuelwood for cooking in commercial entities.

6.2.1 System Boundary

The system boundary for this study starts with the use of a public toilet facility and ends with the biogas combustion in commercial and institutional kitchens. The environmental impact at each stage is accounted for by calculating the GHG and other criteria emissions. The energy used and the environmental impacts associated with the use of equipment in the construction of the toilet facility and biogas plant are not included in this study.

6.2.2 Source of Energy for End Users under the Baseline Scenario

Under the baseline scenario it is assumed that institutions derive energy for their cooking activities from fuelwood. The environmental emissions associated with the use of fuelwood as fuel during cooking are shown in Table 28. The total GHG emissions associated with the use of fuelwood in CO_2eq are1.617 kg CO_2eq.

6.2.3 Human Excreta under the Baseline Scenario

The practice of open defecation which some city dwellers resort to results in human excreta being left in the open environment indiscriminately whose decomposition emits methane into the atmosphere. The GHG and other emission effects from open defecation were estimated based on the findings of the study conducted by Winrock International India (2008) (Table 29).

6.2.4 Biogas Production

The main feedstock for the biogas production process is human waste from the public toilet facility. Each public toilet complex has eight toilet stances, serves about 800 users/day and has one biogas digester attached to it. Biogas production is assumed to be 0.04 m^3/person/day (Bond and Templeton 2011). Assuming 800 users/day/public toilet and assuming operational efficiency of 80%, altogether 7,552 m^3 of biogas/public toilet are produced annually. Thus, four public toilet complexes with 800 users each produce 30,114 m^3 of biogas/year. The biogas is channeled directly to commercial users for cooking and heating. The GHG emissions from the biogas plant include emissions from methane leakage, emissions from biogas production and combustion (Table 30). Based on IPCC (2001), leakage of CH_4 from the biogas plant ranges from 5 to 15%. In this study, a methane leakage of 10% is assumed. Following Zhang and Wang (2014), this study assumes GHG emissions of 4.52 x 10^{-3} kg CO_2-eq/MJ and 1.17 kg CO_2-eq/m^3 of biogas during production and combustion of biogas, respectively.

6.2.5 Net Environmental Impact of the Onsite Energy Generation Model

Emissions under the baseline scenario

Under the baseline scenario, the total emissions are those attributed to emissions from open defecation and emissions

TABLE 28. EMISSION FACTORS FROM COMBUSTION OF FUELWOOD.

EMISSIONS	KG EMISSION/KG OF FUELWOOD
CO_2 emissions	1.513
CH4 emissions	4.14E-03
N_2O emissions	5.52E-05
NO_X emissions	1.38E-03
CO emissions	6.9E-02

Source: IPCC/OECD 1999; Okello 2014.

TABLE 29. METHANE (CH_4) EMISSIONS FROM HUMAN EXCRETA.

SOURCE	UNIT	VALUE
Open defecation	kg/person/day	0.0011
Pit latrine	kg/person/day	0.00046

Source: Winrock International India (2008).

TABLE 30. GHG EMISSIONS FROM A BIOGAS PLANT.

	UNIT	VALUE	SOURCE
Methane leakage	%	10	Pathak et al. 2009
Density of methane	kg/m^3	0.71	Pathak et al. 2009
Emissions from 1 MJ of biogas	kg CO_2-eq/MJ	4.52E-03	Zhang and Wang 2014
Biogas combustion	kg CO_2-eq/m^3	1.17	Zhang and Wang 2014

from the use of fuelwood by institutions. A sum of all these emission levels gives total avoided emissions due to biogas use. The business model also results in environmental emissions which are generated from the processing of the feedstock into biogas. Total savings of GHG emissions are the difference between total avoided emissions and total emissions resulting from the biogas production process.

Table 31 shows the emissions avoided as a result of biogas production using human excreta as feedstock. GHG emissions from open defecation are determined based on the assumption that the total number of persons who previously resorted to open defecation but now served by the four toilet complex are 3,190/day. The annual biogas production from the four toilet complex after accounting for methane leakage is 30,114 m^3. Methane emissions from open defecation are 0.0011 kg/person/day (Table 29). Assuming the total number of operating days is 295, total GHG emissions avoided from open defecation are 21,738 kg CO_2eq/year or 0.71 kg CO_2eq/m^3 of biogas.

Savings in environmental pollution from avoided use of fuelwood are estimated based on the replacement value of biogas to fuelwood. The energy content in 1 m^3 of biogas is 27.44 MJ while in 1 kg of fuelwood, it is 13.8 MJ (IPCC/OECD 1999; Hu et al. 2014). In order to estimate the total value of fuelwood savings, the total amount of fuelwood replaced by biogas is calculated using the heating value/unit of fuelwood and biogas. The net annual biogas production from the toilet facility is 30,114 m^3 which has a potential to replace 59,878 kg of fuelwood. GHG emission savings from avoided use of fuelwood are 96,826 kg CO_2eq (3.22 kg CO_2eq/m^3 of biogas). Total GHG emissions avoided/unit of biogas produced are 3.94 kg CO_2-equivalent/m^3. Avoided emissions from fuelwood usage give the most significant sources of saving in GHG emissions. Savings in other emissions are mostly from avoided use of fuelwood.

Emissions under the biogas model

The main composition of biogas is methane (CH_4) and carbon dioxide (CO_2) and the leakage of these gases from the digester and valves provides a potent emission source during the biogas production process itself. Moreover, GHG emissions are emitted from the use or combustion of biogas during cooking. Table 32 shows GHG emissions from the biogas business model in CO_2-equivalent. The GHG emissions/m^3 of biogas is 1.347 kg CO_2-eq with the highest contribution to GHG emissions originating from combustion of biogas (1.17 kg CO_2-eq).

Net emissions

The biogas plants produce a total of 30,114 m^3 of biogas/year which has a total heating value of 828,908 MJ (energy content in 1 m^3 of biogas is 27.44 MJ). The energy content in 1 kg of fuelwood is 13.8 MJ (IPCC/OECD 1999; Hu

TABLE 31. EMISSION SAVINGS/m^3 OF BIOGAS GENERATED BY THE ONSITE ENERGY MODEL.

SOURCE OF SAVINGS	GHG EMISSIONS	OTHER CRITERIA EMISSIONS		
	CO_2	SO_2	NO_x	CO
Open defecation	0.72			
Use of fuelwood	3.22	0.0139	0.0027	0.137
Total savings	3.94	0.0139	0.0027	0.137

TABLE 32. GHG EMISSIONS/m^3 OF BIOGAS GENERATED (kg CO_2-eq/m^3)

EMISSIONS FROM	GHG EMISSIONS
	CO_2
Methane leakage	0.053[a]
Biogas production	0.124[b]
Biogas combustion	1.170[c]
Total emissions	1.347

[a] Based on methane leakage of 10% and density of methane of 0.71
[b] GHG emission from 1 MJ of biogas energy of 0.00452 kg CO_2eq/MJ
[c] GHG emission from biogas combustion of 1.17 kg CO_2-eq/m^3

et al. 2014) and thus the total amount of biogas from the four toilet complexes has the potential to substitute 60,066 kg of fuelwood, the GHG emissions of which are 97,129 kg of CO_2-eq. Moreover, the toilet complex will serve the population which previously resorted to open defecation the methane emissions of which are 21,343 kg of CO_2-eq. Thus, annual emission saving from avoided fuelwood use and open defecation are 118 tons of CO_2-eq. However, the biogas plant leaks methane of 1,609 kg of CO_2-eq, emits GHG of 3,747 kg of CO_2-eq during production, and 35,343 kg of CO_2-eq during the combustion of biogas. The total GHG emissions from the biogas plants are 40.70 kg of CO_2-eq/year. The net savings of GHG emissions are 77.77 tons of CO_2-eq/year (Figure 8).

Value of carbon credits and other emissions

It is assumed that carbon credits are worth, on average, USD 7/ton of CO_2 equivalent (Table 33). The total annual value of carbon credit is USD 544.

FIGURE 8. GHG EMISSIONS AND SAVINGS FROM FOUR PUBLIC TOILET COMPLEXES WITH BIOGAS PLANT.

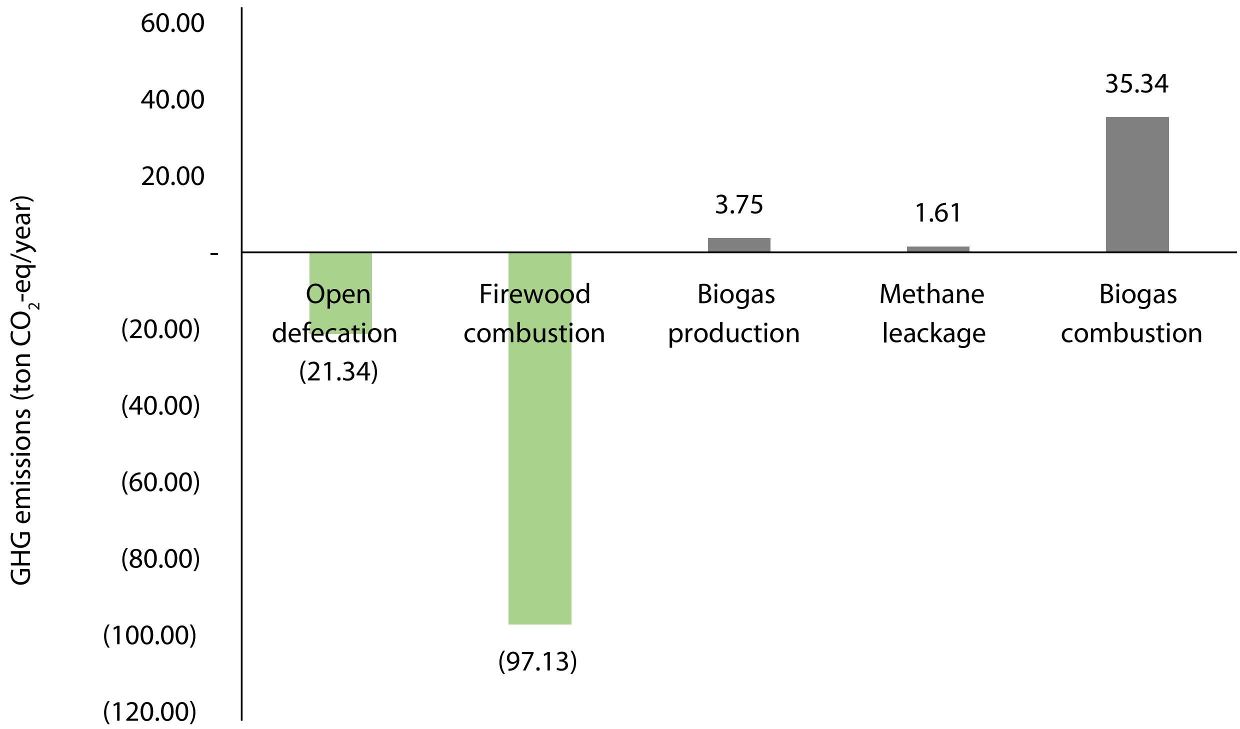


TABLE 33. ANNUAL VALUE OF GHG EMISSION REDUCTION FROM THE ONSITE ENERGY GENERATION MODEL.

ITEM	AMOUNT
Total GHG emission savings (tons of CO_2eq)	118.47
Total GHG emissions from biogas business (tons of CO_2eq)	40.70
Net emission savings (tons of CO_2eq/year)	77.77
Price of VER (USD/tons of CO_2eq)	7
Total value of carbon credit (USD/year)	544

6.3 Social Impacts of the Onsite Energy Generation Model

6.3.1 Savings in Energy Cost for End Users

Using biogas instead of fuelwood has the potential to result in savings for end users. Table 34 shows the potential savings for end users from using biogas. The energy content in 1 m^3 of biogas is 27.44 MJ while the energy content in 1 kg of fuelwood is 13.8 MJ (IPCC/OECD 1999; Hu et al. 2014). In order to estimate the total value of fuelwood savings, the total amount of fuelwood replaced by biogas is calculated using the heating value/unit of fuelwood and biogas. The net annual biogas production from the toilet facility after accounting for methane leakage is 30,114 m^3 which has a potential to replace 59,878 kg of fuelwood. The biogas is assumed to be piped to adjacent institutions (e.g., cafes, restaurants). Each biogas plant is assumed to serve one institutional kitchen which has cooking stoves with a large size (45 kg) gas cylinder. The biogas is sold to institutions at the prevailing price of USD 2.13/m^3 of liquefied petroleum gas (LPG). The LPG equivalent of biogas is assumed to be 0.43 kg (Singh and Sooch 2004). Thus the price of biogas is USD 0.92/m^3. Assuming the efficiency of stoves of 45 and 100%, respectively, when fuelwood and biogas are used for cooking, the actual price/MJ of useful energy is USD 0.039 in fuelwood equivalent and USD 0.033 in biogas equivalent. At the current price of fuelwood (USD 0.24/kg), using biogas has a potential cost saving of 14% as compared to fuelwood used in institutional stoves. Total annual cost savings for end users from utilizing 30,114 m^3 of biogas are estimated to be USD 1,959.

However, shifting to biogas has cost implications for the end users as there is a need for a one-time investment in biogas cooking stoves. The total incremental cost of shifting to biogas is estimated based on the cost of institutional stoves with large-size gas cylinders in Uganda. The total incremental cost to end users is estimated to be USD 1,865/institution. Each biogas plant is assumed to serve one institutional kitchen and thus for the four institutions the total incremental cost is USD 7,461. The switch to biogas from fuelwood use also saves time spent preparing food. Savings in cooking time using biogas compared to biomass fuels average about 1.82 hours/day in Uganda (Habermehl 2008). This makes available extra time to be used for other productive activities. Assuming operating days of 360 days/year and daily wage rate of USD 6.00 for people working in institutional kitchens in Uganda, value of time saved from shifting to biogas is USD 491/institution/year.

6.3.2 Health Expenditure Savings

Using biomass instead of fuelwood or other biomasses has the potential to improve indoor air quality and thus contribute to preventing a number of negative health conditions. Exposure to indoor air pollution from the combustion of fuelwood is a major cause of respiratory diseases, mostly among young children and their mothers (Bruce et al. 2006; Smith et al. 2004). Various studies have pointed to the health impacts associated with exposure to indoor air pollution due to the use of solid fuels (Renwick et al. 2007). Avoiding these health-related expenditures by using clean cooking fuels such as biogas presents savings to the end users. Also found in the literature are a number of studies which have consistently demonstrated that the risk of contracting diarrhea is reduced significantly by 32-45% through sanitation interventions such as the adequate disposal of human excreta (Cairncross et al. 2010; Renwick et al. 2007; Fewtrell et al. 2005). Improvement in water and sanitation facilities has the major advantage of cost savings related to health care mainly due to the reduced number of treatments of diarrhea (Hutton and Haller 2004).

TABLE 34. INCREMENTAL COSTS AND BENEFITS FROM SHIFTING TO BIOGAS FOR END USERS.

	FUELWOOD	BIOGAS
Cost savings from shifting to biogas:		
Fuelwood replaced by biogas (kg) *(A)*	60,066	
Heating value (MJ/unit) *(B)*	13.8	27.44
Unit price (USD/unit) *(C)*	0.24	0.92
Efficiency of stoves (%) *(D)*	45	100
Actual price/useful energy (USD/MJ) *(E=C/(B*D)*	0.039	0.033
Savings from shifting to biogas (%) *(F= 1-E(Biogas)/E(Fuelwood)*	14	
Total energy value of wood replaced *(MJ) (G= A*B*D)*	373,008	
Cost savings from shifting to biogas (USD/year) *(E*F*G)*	1,965	
Incremental cost of shifting to biogas (for four institutions):		
Investment in institutional cooking stoves		1,733
Investment in 45 kg cylinders		132
Total one-time investment on cooking stoves/institution		1,865
Total one-time investment on cooking stoves/four institutions		7,461

6.3.3 Time Savings from Access to Toilet Service

Having access to toilet services results in saving in time spent in accessing a place of convenience away from home or public place (Renwick et al. 2007). Based on studies by Renwick et al. (2007) and Hutton and Haller (2004), it is estimated that 30 minutes will be saved/person/day due to the provision of public places of convenience compared to the baseline scenario of open defecation. In order to value the time gained, an hourly rate of USD 0.22, equivalent to the unskilled rural labor wage rate in Uganda, can be used to estimate the economic value of time gained (Renwick et al. 2007). Based on these assumptions, the public toilet complexes with a potential to serve a total of 3,190 persons/day have the potential to result in time savings of 470,525 hours/year which is valued at USD 103,516.

6.4 Financial Analysis of the Onsite Energy Generation Model

The financial results presented in this section are for four toilet complexes which will serve a target population of 3,190. Each toilet complex has a capacity of serving 800 persons/day and is equipped with a biogas plant with a volume of 54 m^3. Total investment cost/plant is USD 56,000 and includes the toilet facility, biogas digester, a space for rental, labor and materials for construction. Biogas digesters have a useful life of 20 years (Singh and Sooch 2004). However, the toilet stances are assumed to have a useful life of 7 years after which they have to be replaced. The toilet facility is assumed to have eight toilet stances, each toilet costing about USD 417 (NETWAS-U 2011). Investment on toilet facility is done on the 7^{th} and 14^{th} years to replace toilet stances (Renwick et al. 2007; Obel-Lawson et al. 1999). Land required/facility is 100 m^2. Each plant is run by a community-based organization (CBO). Campaigns and training on how to run the facility including training on biogas technology are provided to the members of the community at the beginning of the project year. Total cost for training is USD 10,000/plant (based on Umande trust TOSHA 1 bio-center business case in Kenya). Land is to be granted by the municipality while the investment cost including training is to be funded by developmental agencies and operational costs are to be covered by the community which runs the facility.

Revenue streams for the toilet facilities include fees from toilet use, revenue from biogas use and revenue from rental space (Table 35). Additional revenue could be generated from selling the slurry from the digester; however, in this analysis slurry is not sold. Toilet fee/use in Uganda ranges from USD 0.09 to 0.15 with an average of USD 0.10/use. Daily biogas production depends on daily fecal sludge fed to the digester that, in turn, depends on the number of toilet users. To determine revenue from biogas, the LPG equivalent of biogas produced is calculated and the prevailing price for LPG in Uganda is used. LPG equivalent of biogas is 0.43 kg (Singh and Sooch 2004) and the current LPG price is USD 2.13/kg in Uganda. Moreover, a 20% biogas loss due to leakage or other factors is assumed. In addition to toilet and biogas, the enterprise provides a hall to host meetings as well as a room that individuals can rent to set up their own business. A rental fee of USD 100 /month is assumed.

TABLE 35. INCOME STREAMS AND OPERATIONAL COSTS FOR THE ONSITE ENERGY GENERATION MODEL.

ITEM	UNIT	AMOUNT	REFERENCE
Toilet fee/use	USD/use	0.09-0.14	Sanitation updates, 2011 https://sanitationupdates.wordpress.com/tag/pay-per-use-public-toilets/
Price of LPG	USD/kg	2.13	Prices of LPG in Uganda 2012
Rental	USD/month	50-100	Sustainable Sanitation Alliance 2010; Based on Umande Trust TOSHA business case, Kenya
Toilet supplies	USD/day	4	Based on Umande Trust TOSHA, Kenya
Number of staff	#	2	Sustainable Sanitation Alliance 2010
Labor rate	USD/day/ person	6	Sustainable Sanitation Alliance 2010
Water tariff	USD/liter	0.002	Water tariff in Uganda USD2/1,000 liters
Electricity tariff	USD/KWh	0.20	Electricity tariff in Uganda
Annual exhaustion service	USD/year	380	Based on Umande Trust TOSHA, Kenya
Annual depreciation	%	5	Assuming useful life of 20 years for biogas system
O&M cost	%	5	Assumed

Table 36 presents the financial results of four public toilet complexes with an onsite energy generation serving 3,190 people. A major source of income for the business model is from toilet services which account for 84% of the total revenue while biogas sales account for 12% of the total revenue. Results show that the onsite energy generation business model has the potential to operate under profit and results in a positive NPV and IRR of 25%.

TABLE 36. FINANCIAL RESULTS OF THE ONSITE ENERGY GENERATION BUSINESS MODEL (USD).

	YEAR								
	0	1	2	3	4	5	6	7	...
Capital cost	224,000							13,334	
Fees from toilet use		94,400	94,400	94,400	94,400	94,400	94,400	94,400	
Biogas sales		13,834	14,249	14,676	15,117	15,570	16,037	16,518	
Rental		4,800	4,944	5,092	5,245	5,402	5,565	5,731	
Total revenue		113,034	113,593	114,169	114,762	115,372	116,002	116,650	…
Operational costs:									
Campaign/training	40,000								…
Operational costs		52,712	54,293	55,922	57,600	59,328	61,108	62,941	…
Operating profit		60,322	59,299	58,246	57,162	56,045	54,894	53,709	…
Cash flow	(264,000)	71,522	70,835	69,128	69,400	68,650	67,878	53,738	…
ROI		27%	26%	26%	26%	25%	25%	24%	…
NPV		185,946							
IRR		25%							

6.5 Consolidated Socioeconomic Results of the Onsite Energy Generation Model

The potential socioeconomic impact of the onsite energy generation model serving 3,190 end users is presented in Table 37. The business model is financially and economically feasible showing positive NPV and BCR greater than 1. Moving from the financial results to including the environmental impacts, the incremental benefit from the GHG emission savings (benefit from carbon credit) is minor showing an increase in NPV of only 2% (USD 190,013). In contrast, NPV increased by 93% and ROI by 34% when the social benefits associated with savings for end users and value of time savings are accounted for. The social benefits include savings in energy costs for end users and value of time savings. The social benefits associated with time savings comprise time savings for toilet users and biogas users. The public toilet complexes with a potential to serve a total of 3,190 persons/day have the potential to result in time savings of 470,525 hours/year which is valued at USD 103,516 assuming a wage rate of USD 0.22/hour for unskilled labor in Uganda. Savings in cooking time using biogas compared to biomass fuels average about 1.82 hours/day in Uganda (Habermehl 2008). The value of the social benefit from the onsite energy generation model is USD 3.73/m^3 of biogas produced.

7. SENSITIVITY ANALYSIS - STOCHASTIC SIMULATION

To assess the sensitivity of the results to variation in input variables such as the price of inputs and outputs, price of carbon credit, price of fuelwood and other variables, a simulation model of each business model is developed using the Monte Carlo simulation model. Using this simulation model, the uncertainty of variations in input cost and price of outputs was incorporated into the socioeconomic assessment. The simulation model allows one to specify distributions for stochastic variables.

7.1 Stochastic Variables

Table 38 presents the stochastic variables and the distribution assumed for the variables. It is assumed that the price of briquette varies from USD 0.20-0.40/kg with the average price of USD 0.282/kg based on observed prices charged by existing briquette plants in Uganda (Ferguson 2012). Input cost for briquette making ranges from a minimum of USD 0.10/kg to a maximum of USD 0.20/ton with a mean price of USD

TABLE 37. NET SOCIOECONOMIC RESULTS OF THE ONSITE ENERGY GENERATION MODEL.

SOCIOECONOMIC RESULT (USD/YEAR)	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	SOCIAL, ENVIRONMENTAL AND FINANCIAL VALUE
Financial result:			
NPV	185,946	185,946	185,946
Environmental benefit:			
Value of net GHG emission saving		4,066	4,066
Social benefit:			
Savings in energy costs for end users			7,220
Value of time savings for toilet users			103,516
Value of time saving for institutional biogas users			1,966
Total value of social benefit			112,702
BCR	2.11	2.13	2.63
NPV	185,946	190,013	302,717
ROI (average)	22%	22%	29%

TABLE 38. STOCHASTIC VARIABLES IN THE SIMULATION MODELS.

VARIABLE	UNIT	VALUE RANGES	SOURCE
Dry fuel manufacturing:			
Price of briquette	USD/kg	0.20-0.40	Ferguson 2012; Based on existing plant of similar scale in Uganda
Input cost for briquette	USD/ton	0.10-0.20	Based on existing plant of similar scale in Uganda
ESCO model:			
Price of electricity	USD/KWh	0.25-0.33	Buchholz and Volk 2007
Capital cost of gasifier	USD	2,010-2,890	Buchholz and Volk 2007; IFAD 2010
Input cost (feedstock)	USD/kg	0.014-0.022	Assumed
Onsite energy generation:			
Cost of toilet stances	USD/toilet stance	417-625	NETWAS-U 2011
Number of toilet users/	Number/day	600-1,000	Based on public toilets in Uganda and TOSHA bio-center in Kenya
Biogas yield	m^3/person/day	0.035-0.05	Bond and Templeton 2011
Biogas sales	% of production	50-100%	Assumed
Likelihood of revenue from rental	#	(1, 0.5)	Assumed
Other variables:			
Price of fuelwood	USD/kg	0.11-0.24	GVEP International 2010
Carbon credit price	USD/kg CO_2-eq	5-9	World Bank 2014

0.129/kg. The price of fuelwood varies from USD 0.11 to 0.24/kg (GVEP International 2010). Based on World Bank (2014), carbon credit prices in the EU ETS ranged from USD 5 to 9 (€4-7)/ton of CO_2-eq in 2014. A triangular distribution was used to model the price ranges.

It is assumed that the price of electricity from the ESCO model varies from USD 0.22 to 0.33/kWh based on literature and observed prices in Uganda (Buchholz and Volk 2007). The initial investment cost for the gasifier varies from USD 2,010 to 2,890/kWh installed. The cost of input varies from USD 0.014 to 0.022/kg.

Under the onsite energy generation model, the toilet stances are to be replaced after 7 years which require additional investment. The cost of a toilet stance in Uganda ranges from USD 417 to 625 depending on the availability and price of materials (NETWAS-U 2011). The major source of revenue for the business is from toilet fees. Based on experience from similar public toilet facilities in Uganda and Kenya, the number of toilet visitors varies from a minimum of 600 and a maximum of 1,000/day. Experience in Kenya shows that toilet facilities with biogas plants may not sell/utilize all the biogas produced. In our analysis, we assume that biogas use is 100% of production under an optimistic scenario and 50% under a pessimistic scenario. Biogas yield ranges from 0.035 to 0.05 m^3/person/day (Bond and Templeton 2011). Another source of revenue which is also uncertain is that from rent. We assumed a binary distribution for rent with a likelihood of 0.5.

7.2 Simulation Results of Business Models

Simulation results provide the expected values for each of the valuation criteria, estimates of the variability of the criteria and the probability of economic success. The simulation results of each of the business models analyzed are presented in the following sections.

7.2.1 Simulation Results of the Dry Fuel Manufacturing Model

Table 39 shows the simulation results for NPV, ROI and BCR valuation criteria. The risk analysis showed a mean NPV of USD 0.225/million with a variability from 0.53 to USD 1.00/million (90% confidence interval) when only direct benefits and costs are taken into account. When environmental and social benefits and costs were taken into account, the business model performed better and resulted in a mean NPV of USD 0.679/million, a BCR of 3.41 and ROI of 47%. The risk analysis showed that the most important variable with a significant effect on NPV values is the price of briquettes followed by the price of fuelwood when indirect costs and benefits are taken into account. Thus, in addition to the price of briquettes, the price of fuelwood has an impact on the socioeconomic viability of the business model as the briquettes are used either as a replacement or as a complement to fuelwood. This implies that regulations on fuelwood use and price trends in Uganda have a direct impact on the socioeconomic viability of briquette businesses.

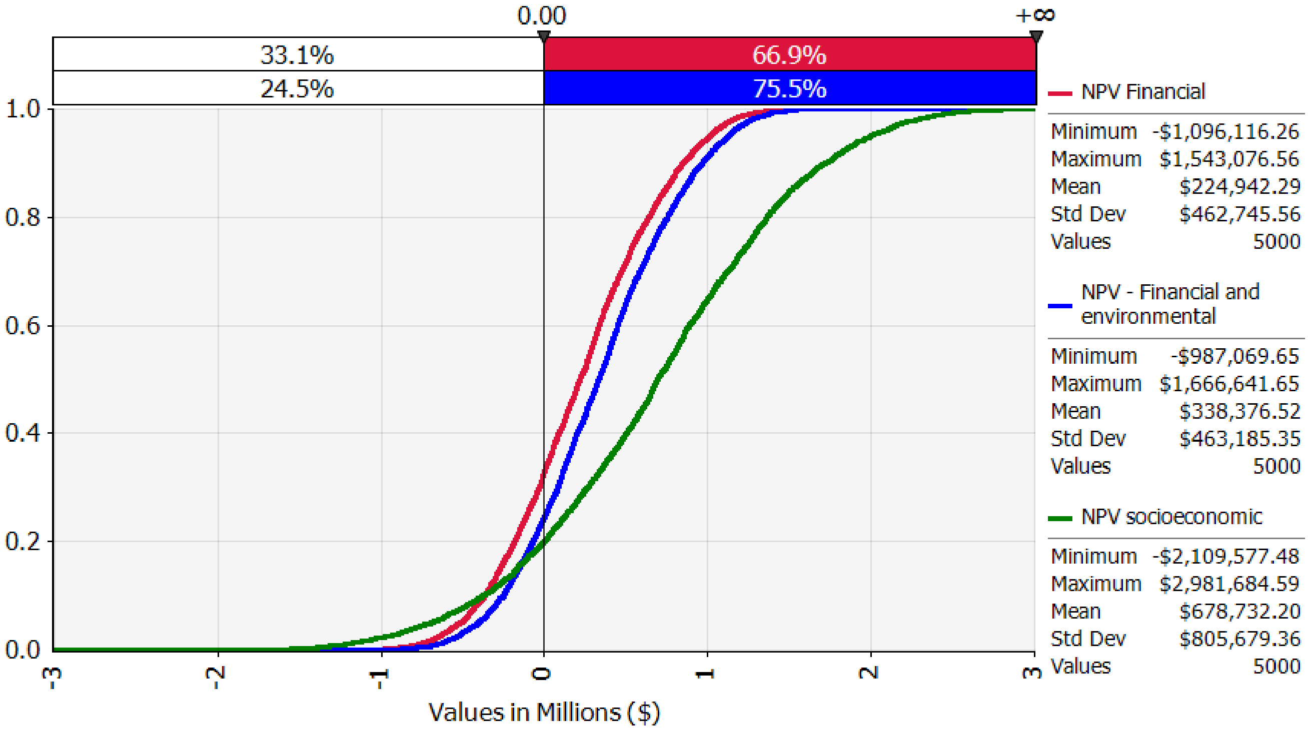
The simulation model provides, in addition to mean values, a clear understanding of the variability of the valuation criterion and the probability distribution. Figure 9 shows the probability density function of NPVs when direct and indirect benefits and costs are taken into account. The probability of a negative NPV when only direct benefits and costs are taken into account is 33% and this decreases to 24% when environmental costs and benefits are included and to 20% when social benefits and costs are included. Thus from a socioeconomic perspective, investing in the dry fuel manufacturing business is economically viable with a potential of attaining an NPV of USD 1.99 million under optimistic scenarios and has a probability of more than 80% of economic success.

TABLE 39. SIMULATION RESULTS OF THE DRY FUEL MANUFACTURING MODEL.[a]

	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	FINANCIAL, ENVIRONMENTAL AND SOCIAL VALUE
NPV-mean (million USD)	0.225	0.338	0.679
5%	-0.53	-0.42	-0.69
95%	1.00	1.11	1.99
BCR-mean	1.86	2.25	3.41
5%	-1.03	-0.66	-1.47
95%	4.84	5.23	8.11
ROI-mean (%)	25	31	47
5%	-20	-15	-18
95%	73	78	107

[a] 5000@Risk iterations.

FIGURE 9. PROBABILITY DENSITY FUNCTION OF NPVs FOR DRY FUEL MANUFACTURING MODEL.



Note: Std Dev=Standard deviation.

7.2.2 Simulation Results of the ESCO Model

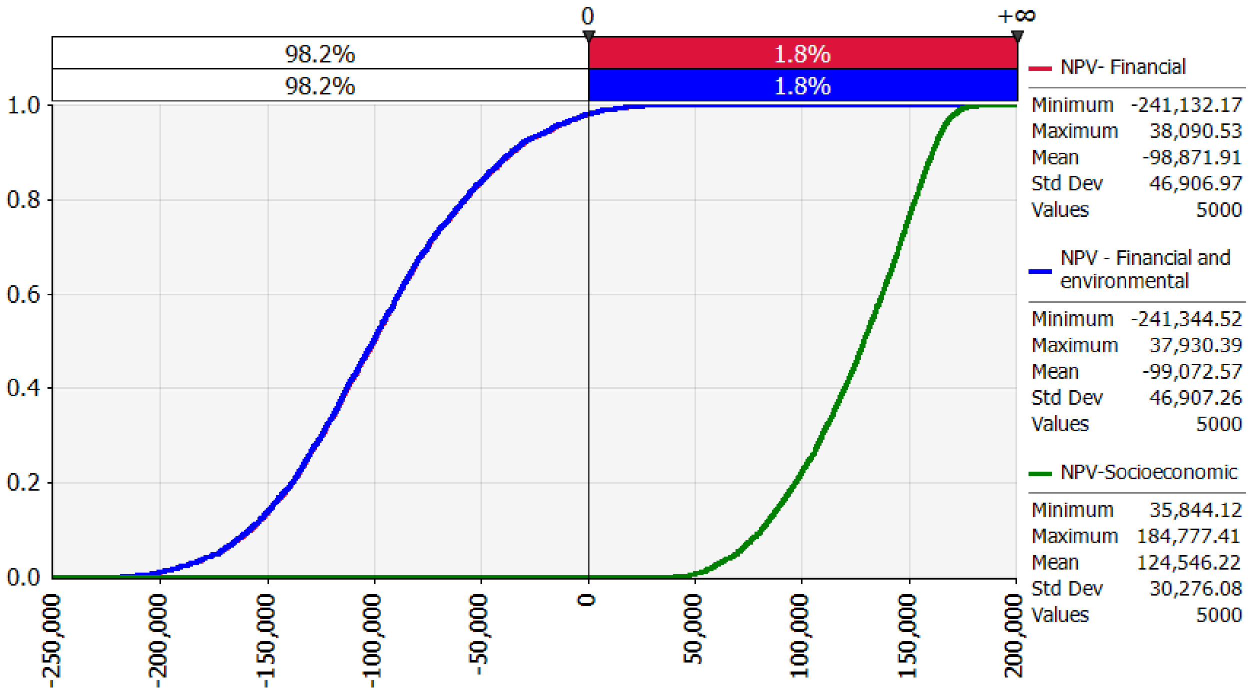
The net returns of the ESCO model are highly negative when financial and environmental costs and benefits are taken into account (Table 40). Mean NPV is USD -98,872 with variation from -173,540 to USD -17,420 when only direct benefits are taken into account. Adding the environmental costs and benefits of the business model brings minor changes to the performance of the business as the results are still highly negative. When social benefits are taken into account, the business model results in a mean positive NPV and BCR greater than 1. As shown in Figure 10, the probability of a negative NPV when financial and environmental costs and benefits are taken into account is 98.1% and this significantly decreases to 0% when social costs and benefits are included. Thus from a socioeconomic perspective, investing in the ESCO business is economically viable with a potential of attaining an NPV of USD 0.167 million under optimistic scenarios and a probability of economic success of 100%. The risk analysis showed that the most important variable with a significant effect on the financial viability of the business model is the price of electricity. Input cost did not have a significant impact on the financial viability of the business model. In addition to the price of electricity, the variation in the initial cost of the gasifier plant has a significant effect on the socioeconomic viability of the business model.

TABLE 40. SIMULATION RESULTS OF THE ESCO MODEL.[a]

	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	FINANCIAL, ENVIRONMENTAL AND SOCIAL VALUE
NPV-MEAN (MILLION USD)	-98,872	-99,072	124,546
5%	-173,540	-173,736	68,318
95%	-17,420	-17,596	166,579
BCR-MEAN	0.70	0.70	1.30
5%	0.51	0.51	1.10
95%	0.95	0.95	1.50
ROI-MEAN (%)	5	5	13
5%	2	2	11
95%	9	9	15

[a] 5000@Risk iterations

FIGURE 10. PROBABILITY DENSITY FUNCTION OF NPVs FOR ESCO MODEL.



Note: Std Dev = Standard deviation.

7.2.3 Simulation Results of the Onsite Energy Generation Model

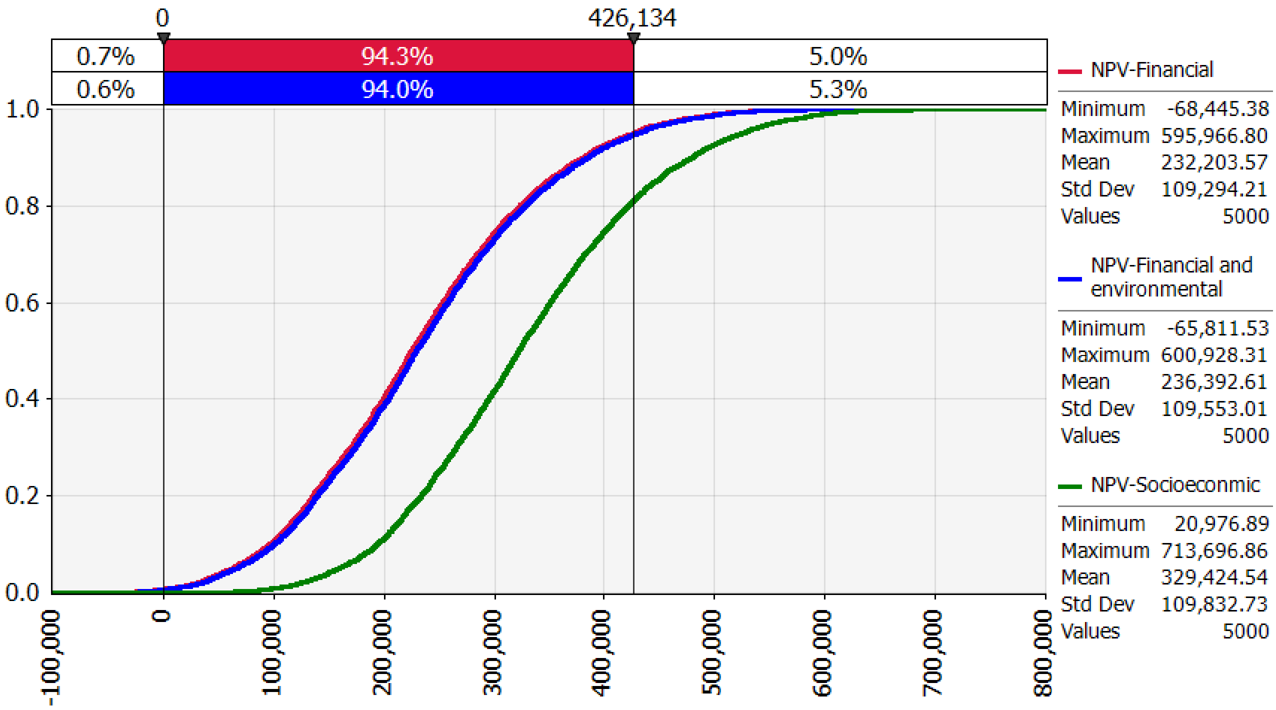
The net returns of the onsite energy generation model is positive from both financial and socioeconomic perspectives (Table 41). The business has the potential to result in a positive mean NPV and has a more than 99% chance of economic success as indicated by P(NPV<0) not only when indirect benefits and costs are included but also when only direct benefits and costs are taken into account (Figure 11). Thus the onsite energy generation model is financially and economically feasible. The risk analysis showed that the most important variables with a significant effect on the financial viability of the business model are the number of toilet users/day and fees charged to toilet users. In addition to these variables, the variation in price of fuelwood has a significant effect on the socioeconomic viability of the business model.

TABLE 41. SIMULATION RESULTS OF THE ONSITE ENERGY GENERATION MODEL.[a]

	FINANCIAL VALUE	FINANCIAL AND ENVIRONMENTAL VALUE	FINANCIAL, ENVIRONMENTAL AND SOCIAL VALUE
NPV-MEAN (MILLION USD)	0.232	0.236	0.329
5%	0.061	0.065	0.157
95%	0.429	0.433	0.528
BCR-MEAN	2.34	2.36	2.77
5%	1.49	1.50	1.90
95%	3.32	3.39	3.75
ROI-MEAN (%)	25	25	31
5%	13	14	20
95%	38	38	44

[a] 5000@Risk iterations

FIGURE 11. PROBABILITY DENSITY FUNCTION OF NPVs FOR ONSITE ENERGY GENERATION MODEL.



Note: Std Dev = Standard deviation.

8. DISCUSSION AND CONCLUSION

This study assessed the socioeconomic impact of three energy business models: the dry fuel manufacturing business model, the Energy Service Company (ESCO) model and the onsite energy generation in enterprises providing sanitation services in Kampala, Uganda. The socioeconomic analysis is conducted based on the valuation of environmental, social and financial benefits and costs associated with the business models.

Table 42 presents the consolidated social, environmental and financial benefits of the three energy business models. These business models using different waste streams have different scales and produce different products with varying uses. The dry fuel manufacturing business and the onsite generation model were found to be financially and economically viable while results showed that the ESCO model was not financially viable due to the high investment cost and low electricity prices. The ESCO model was economically the least beneficial with a BCR of 1.35 and ROI of 14% when the externalities are included in the economic analysis.

The environmental impacts associated with the dry fuel manufacturing business model were estimated based on emissions avoided from fuelwood combustion and open burning of agricultural residues net of emissions from the briquette business which included transportation of agricultural residues, briquetting, transportation and combustion of briquettes. The major contribution to GHG emission savings is from avoided use of fuelwood. For other criteria emissions, major savings are from avoided burning of agricultural residue in the open fields. The combustion of briquettes in stoves contributes the highest GHG and other criteria emissions. Using efficient cook stoves for combustion of the briquettes and improving the combustion efficiency of the briquettes could reduce the life cycle emissions of the briquette fuels. Compared to the baseline scenario, the briquette business resulted in a net GHG emission saving of 1.19 kg CO_2eq/kg of briquette. The dry fuel manufacturing business model, in addition to combating deforestation and climate change, generates additional income for farmers, creates jobs for local residents, and enables end users to save on energy costs as well as improving the cooking environment. Looking at the overall socioeconomic impacts, the dry fuel manufacturing business model is both financially and economically feasible. There is a significant increase in the economic feasibility of the business due to social and environmental benefits associated with the business. The business model has a potential to result in social NPV of USD 1.4 million and ROI of 85%. The major contribution to the

TABLE 42. COMPARISONS OF THE SOCIOECONOMIC RESULTS OF ENERGY BUSINESS MODELS

SOCIOECONOMIC RESULT	ENERGY BUSINESS MODELS		
	DRY MANUFACTURING	ENERGY SERVICE FUEL COMPANY (ESCO)	ONSITE ENERGY GENERATION
Financial result:			
NPV (USD)	256,480	(130,823)	185,946
BCR	1.98	0.58	2.11
ROI (%)	27	3	22
Environmental benefit (USD):			
Value of net GHG emission saving	113,434	(201)	4,066
Social benefit (USD):			
Savings in energy costs for end users	522,719	40,637	7,220
Additional income to farmers	128,650	122,813	
Value of employment	269,710	72,128	
Value of time savings for end users			105,482
Savings in health expenditure for households		12,044	
Government tax revenue	149,026	20,931	
Financial, environmental and social:			
BCR	6.02	1.35	2.63
NPV (USD)	1,440,019	137,530	302,717
ROI (%)	85	14	29

economic feasibility of the business is from the social benefits with major benefits coming from the savings in energy costs to end users.

The ESCO model, when only the direct benefits are accounted for, results in negative NPV implying that the business model is not financially feasible. Moreover, the business model resulted in higher GHG emissions and thus higher environmental costs compared to the baseline scenario. However, the net incremental costs from the environmental impacts are not high enough to bring a change in the performance of the business model. The business model becomes economically feasible when social benefits and costs are included in the analysis. From the socioeconomic perspective, the use of agricultural residues as a feedstock in a small-scale biomass gasification to produce electricity is viable in Uganda and has the potential of positively impacting the health and social life of peri-urban and rural dwellers. The business model resulted in a BCR of 1.35 and ROI of 14% indicating that although not all social impacts have been factored in the analysis, the business model results in positive social impacts that offset its costs. Exclusion of social benefits and costs associated with the business model could lead to erroneous investment decisions and thus should be taken into account in project implementations.

The environmental impacts associated with the onsite energy generation business model were estimated based on emissions avoided from fuelwood combustion and open defecation net of emissions from the business model. Emissions from the business model accounted in this study included emissions associated with methane leakage, biogas production and combustion. The major contribution to GHG emission savings and other criteria emission is from avoided use of fuelwood which accounted for 81% of the avoided GHG emissions. The combustion of biogas in stoves contributes the highest GHG emissions. Compared to the baseline scenario, the business model results in net GHG and other criteria emission savings. Although there is a need for additional investment in cooking stoves for end users when shifting to biogas, the estimated value of net savings in energy costs is higher than the one-time investment in cooking stoves. Thus the business model has a positive social impact to end users through the delivery of improved sanitation services and cleaner energy for cooking which resulted in savings in energy costs for end users and saving in time spent accessing a toilet and in cooking. Looking at the overall socioeconomic impacts, the business model is both financially and economically feasible. There is a significant increase in the economic feasibility of the business due to social and environmental benefits with a major contribution to the economic feasibility of the business coming from the social benefits associated with the business model.

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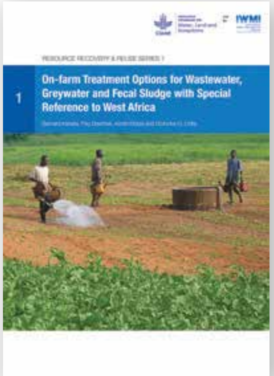

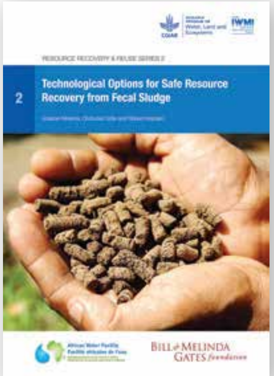

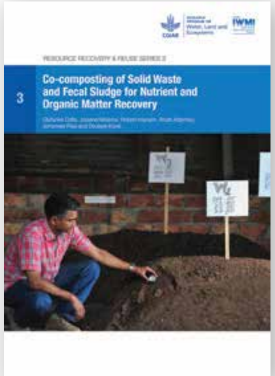

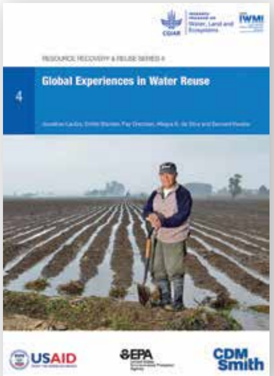

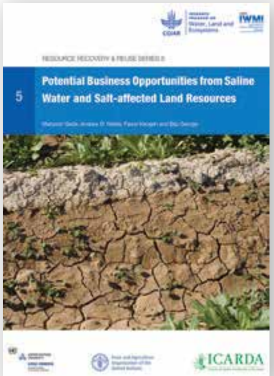

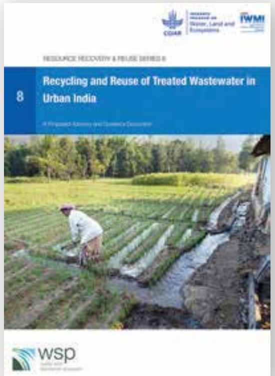

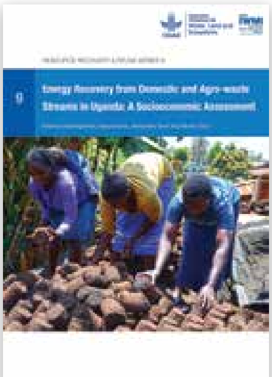

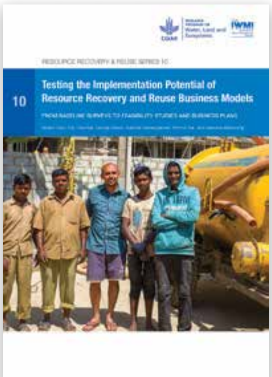

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